ENERGY in the 21st Century: Need for bold thinking & action

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Special thanks to

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The scale of global energy needs and the associated infrastructure is mind-boggling

The pace of change of resource availability and competition necessitates new paradigms

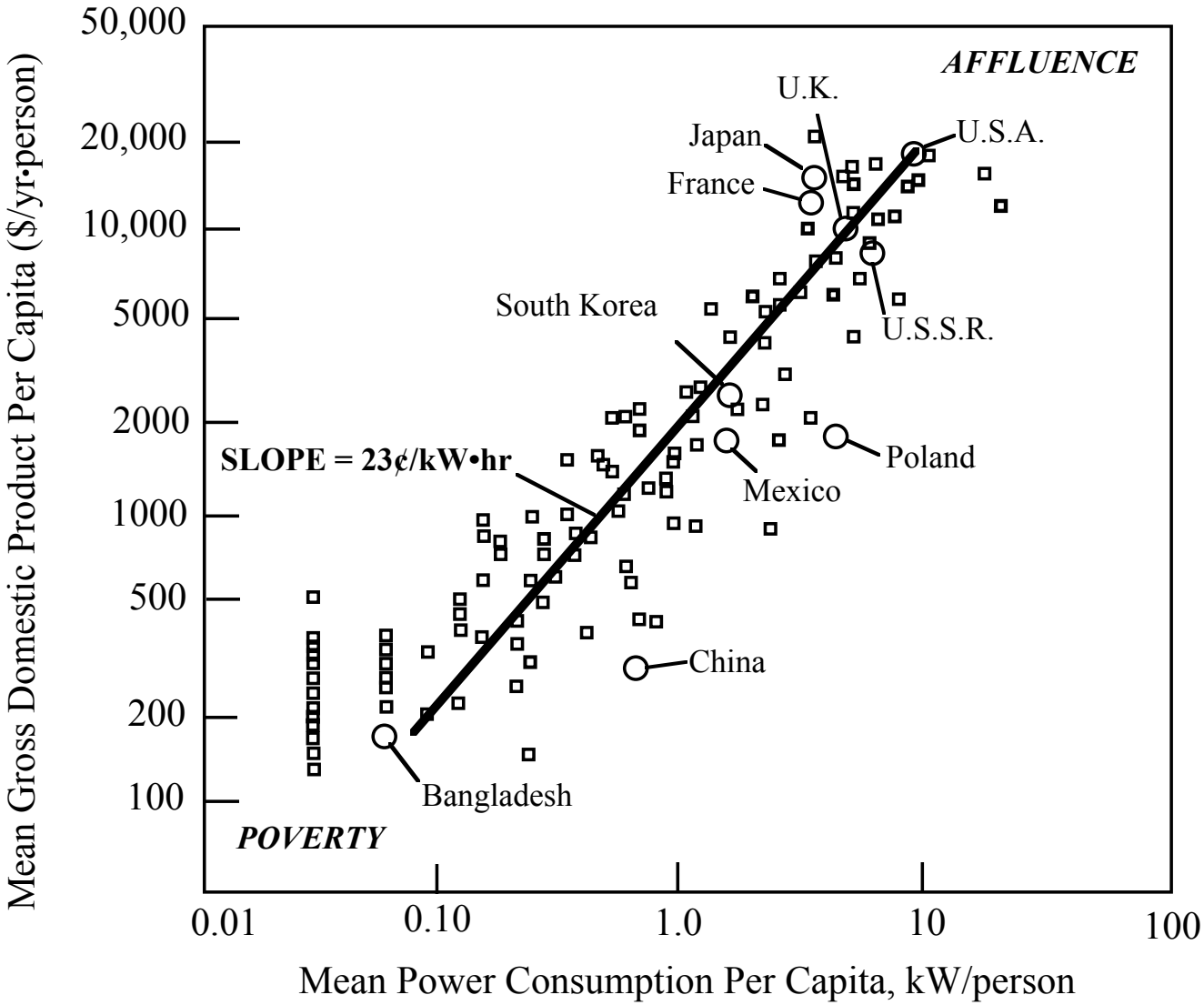
Huge inertia in energy sector

- Oil contracts, rigs, exploration technology
- Tankers and pipelines
- Refineries
- Auto industry
- 600 million cars running on gasoline
- Service stations and gasoline stations
- Existing coal/gas electricity generation plants

The existing investment of >$10 trillion in oil cannot be changed overnight

Energy and potable water are two key resources necessary not just for development but for preserving the modern way of life itself

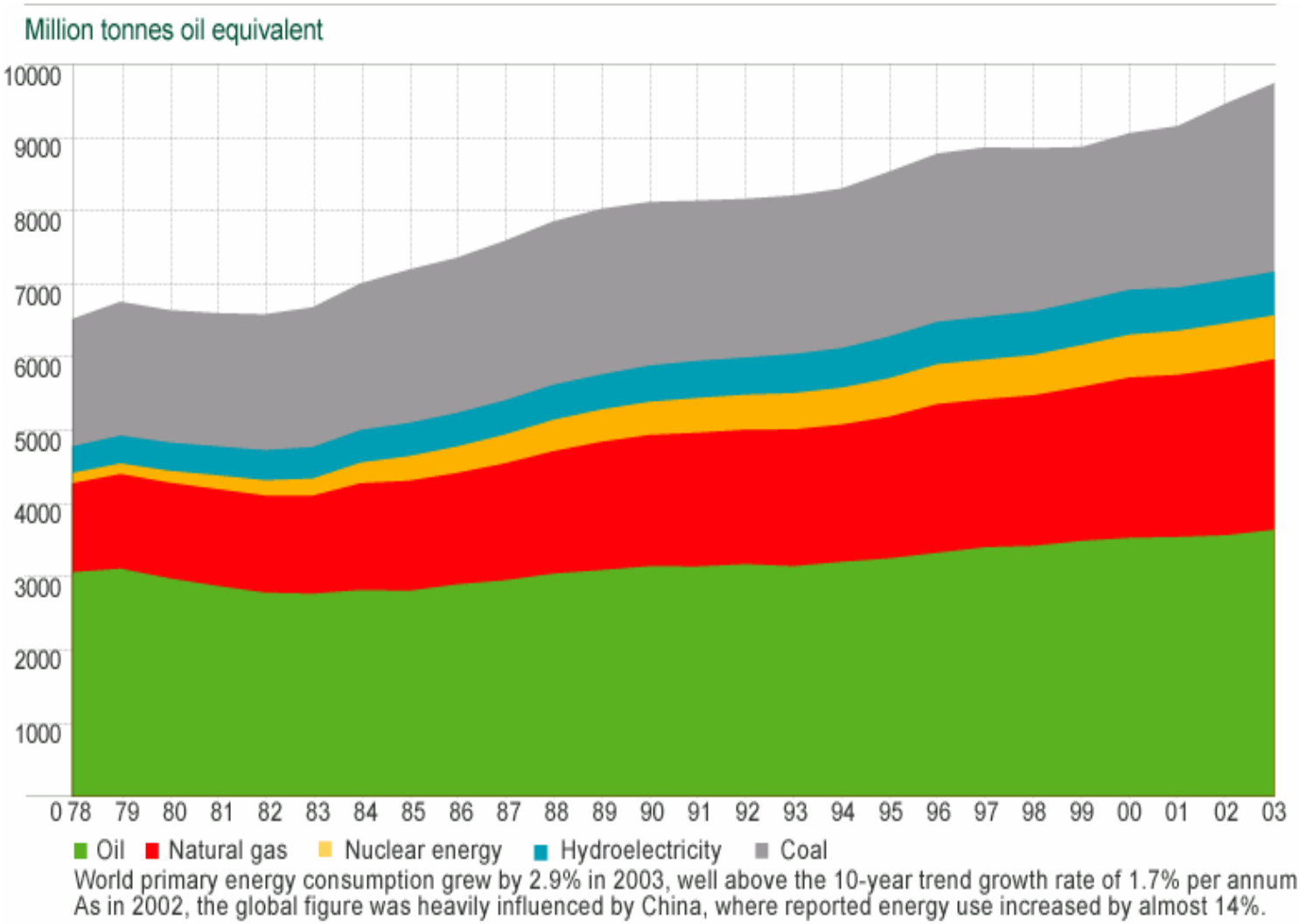
Correlation between energy use and wealth



NEED 3X

To sustain 8 billion people expected by 2025 @ 5 kw/person we will need >3 times today's (12Tw) power

2% growth in world primary energy consumption



Coal

Hydro

Nuclear

GAS

OIL

BP 2004

Energy Profile
(Share of total energy)

Country Region	Oil %	Gas %	Coal %	Hydro %	Nuclear %	Other %
China	19.9	2.8	55.9	2.1	0.4	18.9
India	21.1	4.4	33.8	1.2	0.9	38.6
EU	40.6	23.2	14.6	2	15.6	4.0
USA	39	24	23	3	8	3.0

1 ton of oil (7.33 barrels) $\rightarrow$ 4.5 megawatt hour in modern plants

1 ton of hard coal $\rightarrow$ 3.0 megawatt hour

1 ton of gas (1380 m^3) $\rightarrow$ 9.0 megawatt hour in CCPP

Consumption of fossil fuels: The holes we are digging

- OIL: 82 million barrels/day
- GAS: 260 billion cubic feet/day
- Coal: 13.7 million tons/day

- OIL: $1.7 \times 1.7 \times 1.7$ km^3/year
- GAS: $1.7 \times 1.7 \times 1.7$ km^3/year (as liquid)
- COAL: $1.6 \times 1.6 \times 1.6$ km^3/year

CO_2 Sequestration needs roughly 3 times the mass/volume

21st century: a time of transition

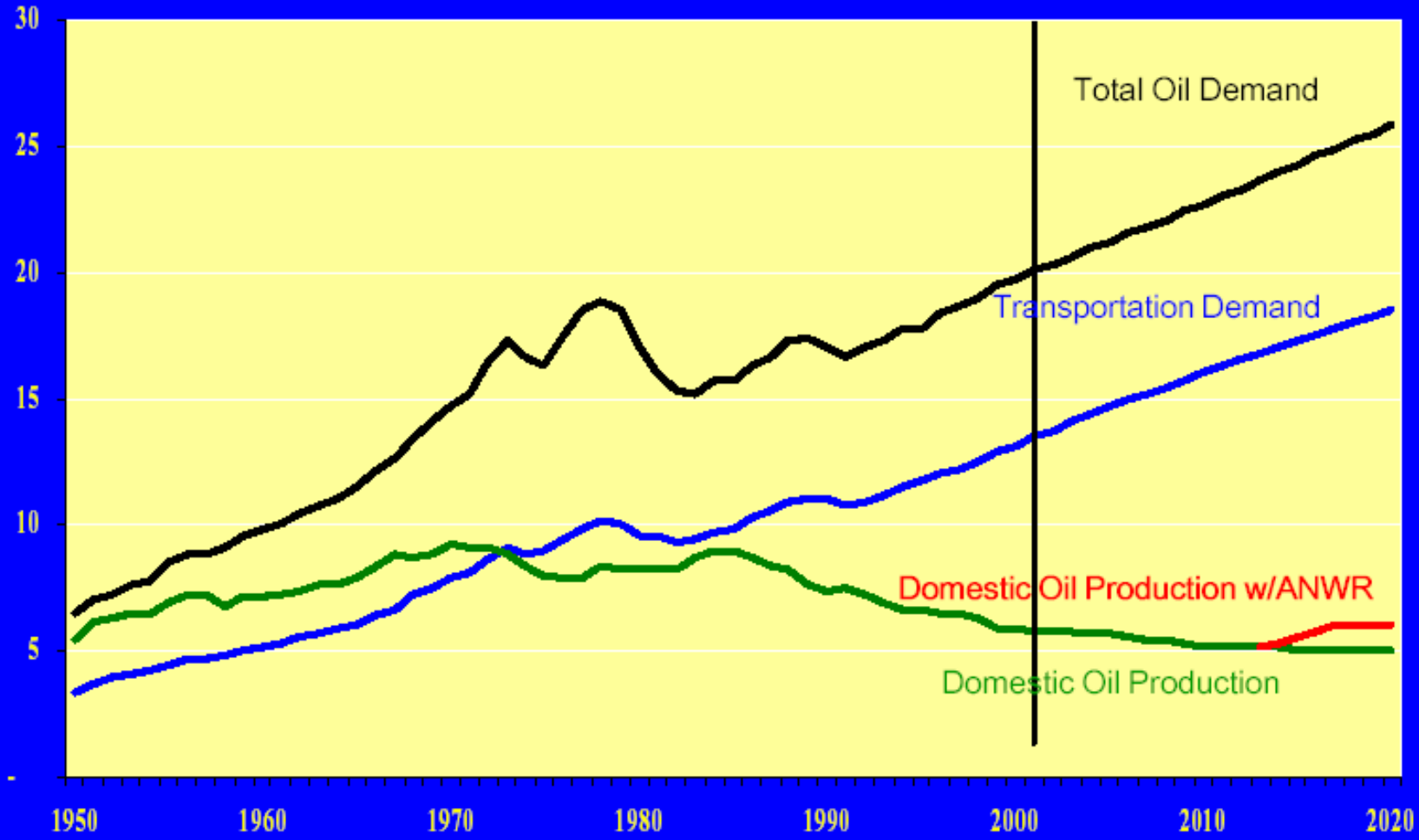
- Fossil fuels, along with hydro and nuclear, fueled the 20th century
- The "other" fuels of 20th century are going to be the fuels by the 22nd century (possibly well before)
- The first half of 21st century is key to this transition
- The questions today are
  - What is the "other"
  - How to pick winners in the mix that defines "other"
  - How to grow these within the context of the existing enormous fossil energy infrastructure

What is driving change

- **OIL:** Global oil production is expected to peak by 2010 while demand is increasing at ~2%!
- NATURAL GAS: expected to peak by 2025
- COAL: pollution → global climate change
- > 65% of remaining oil and gas reserves are in the Middle East and Russia
- USA will face increasing competition for oil and gas from China, India, Europe, …
- Business as usual: nuclear+solar+wind cannot cover expected shortfall in next 10 years

No good alternative to oil for Transportation

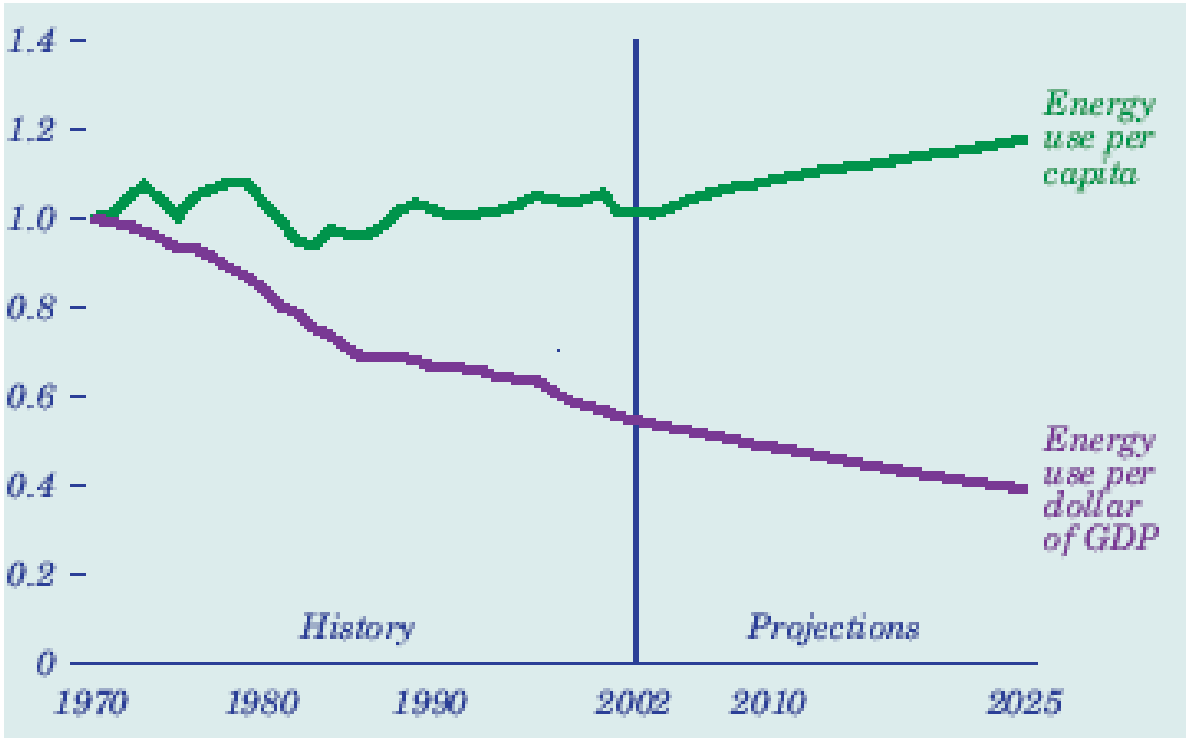
US Oil Consumption (million barrels per day)



EIA, Annual Energy Outlook 2001; "Potential Oil Production from the Coastal Plain of ANWR," - EIA Reserves & Production Division

Energy Use

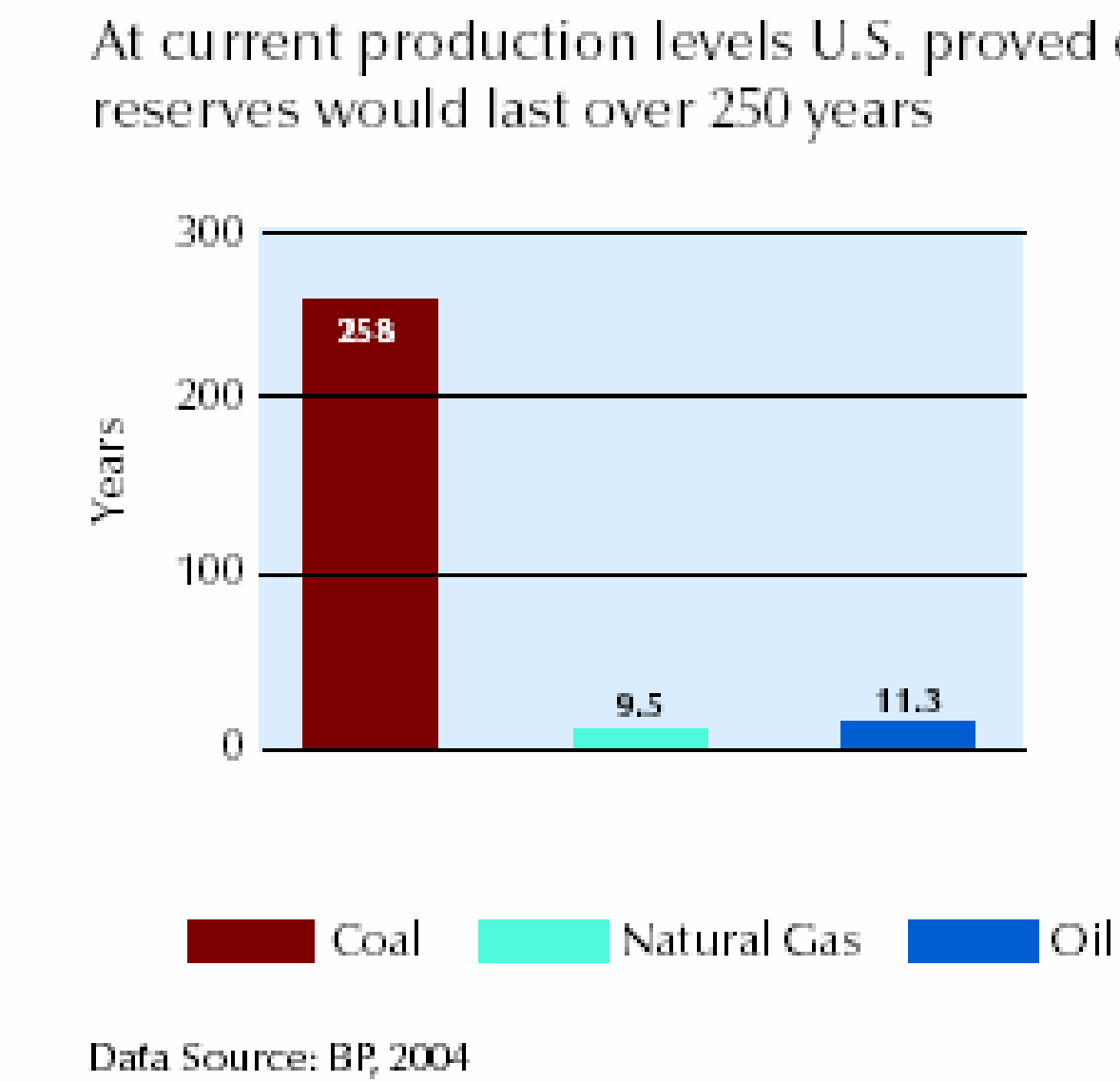
Figure 3. Energy use per capita and per dollar of gross domestic product, 1970-2025 (index, 1970 = 1)



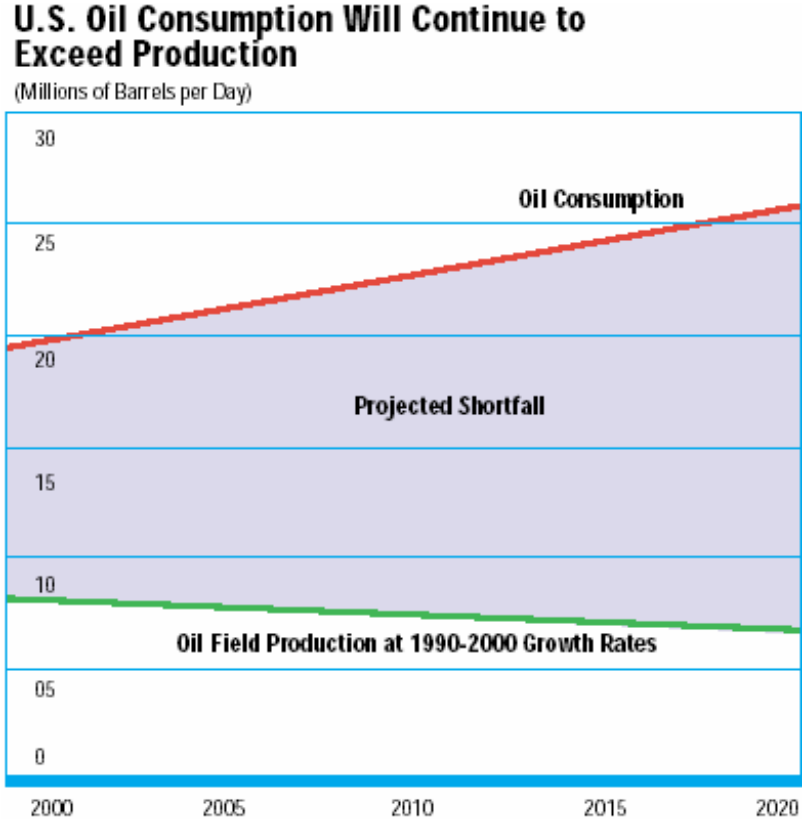
US Population (1970→ 205M; 2004→290M)

Largest increase is in transportation, where there is scope for very significant increase in efficiency.

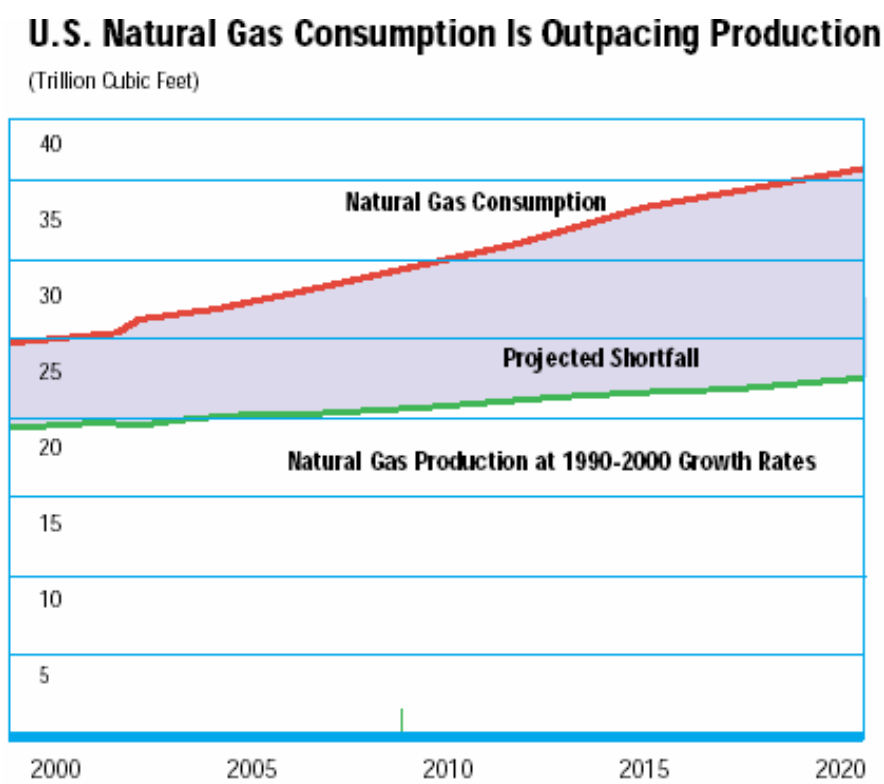
The problem: R/P timeline



We are increasingly dependent on imports for both oil and gas



Over the next 20 years, U.S. oil consumption will grow by over 6 million barrels per day. If U.S. oil production follows the same historical pattern of the last 10 years, it will decline by 1.5 million barrels per day. To meet U.S. oil demand, oil and product imports would have to grow by a combined 7.5 million barrels per day. In 2020, U.S. oil production would supply less than 30 percent of U.S. oil needs.



Over the next 20 years, U.S. natural gas consumption will grow by over 50 percent. At the same time, U.S. natural gas production will grow by only 14 percent, if it grows at the rate of the last 10 years.

Source: NEP May 2001

Key Questions

- Can we continue to consume and assume that alternatives will be in place in time?
- Should change be left to market forces?
  - Higher gas prices → people buy more fuel efficient cars and drive less
  - Declining oil and gas → switch to [clean] coal and non fossil sources
- What new technology should we push?
- How real are the possibilities of major disruptions due to global climate change?

Overall Message

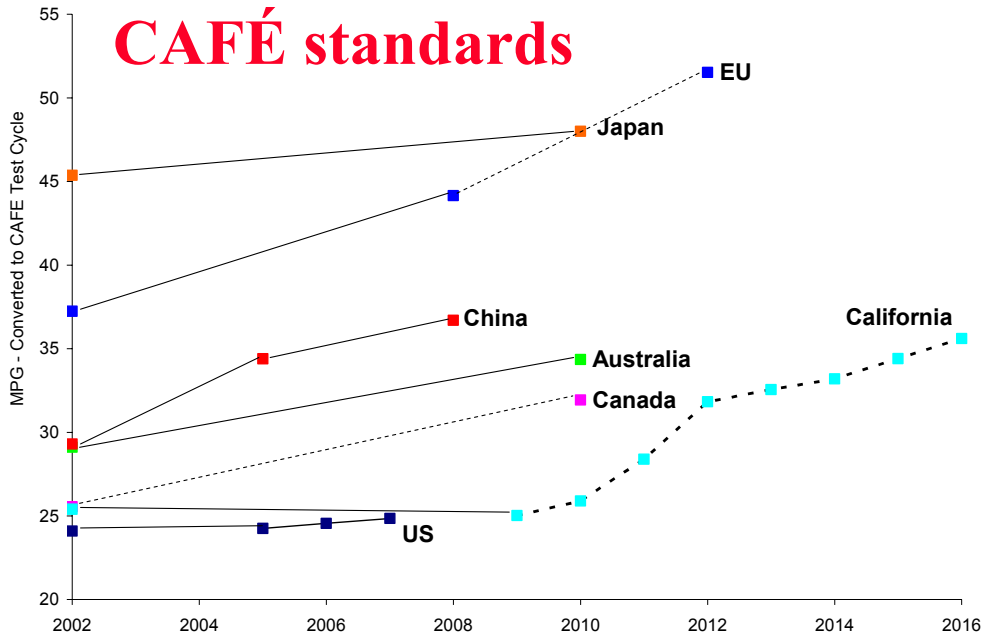
A national "Manhattan/Man on the Moon" program to

- Switch power generation to clean coal & gas, nuclear and renewables
- Develop carbon capture and storage
- Improve fuel efficiency in transport
- Modernize transmission infrastructure
- Develop alternate storage technology
- Preserve oil for future needs in industrial processes and petrochemicals

Message

- There is no one solution
- There is no easy solution
- Solution: accumulation of many changes

The important question is whether we want a planned solution or a forced upon solution



Source: An and Sauer, Pew Center

KEY IMMEDIATE QUESTION?

Is there abundant oil remaining?

Or are alarmists crying wolf again?

If oil reserves are finite, when will decline begin?

Debate: are there 1.0 or 1.7 tera barrels of recoverable oil remaining globally?

Unfortunately, the difference buys the world only 20 more years at current rates of withdrawal!

What has changed since 1970s

- Much more of the world has been surveyed extensively for oil and gas
- Many large oil fields are in decline.
- Saturation of refining and shipping capacity
- Recent rapid growth and competition from China, India, and other developing regions
- Most of the excess capacity is in very unstable and volatile parts of the world – Middle East, Russia, Central Asia, Africa, Latin America

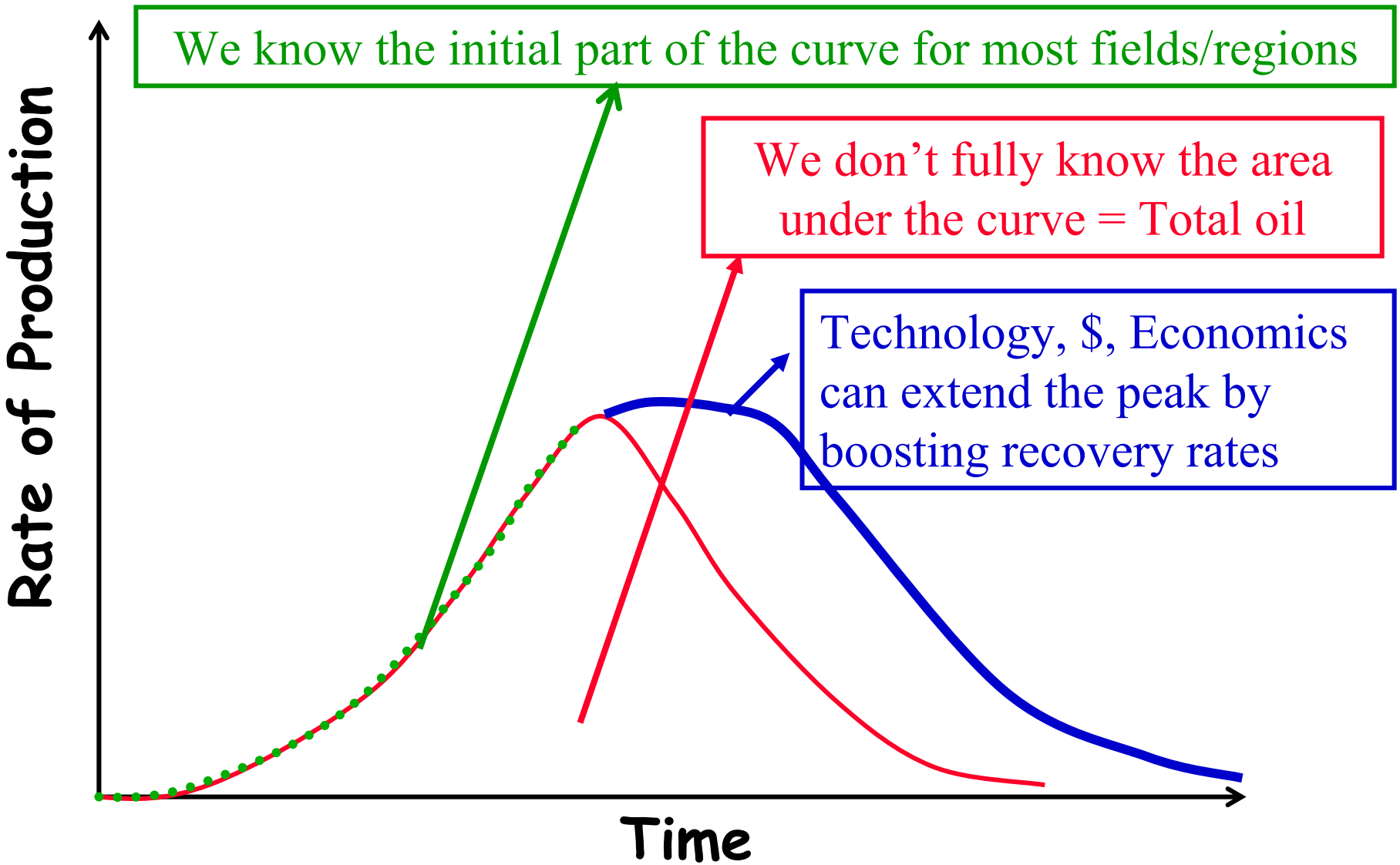
Are oil and gas reservoirs finite?

Biotic formation of oil and gas

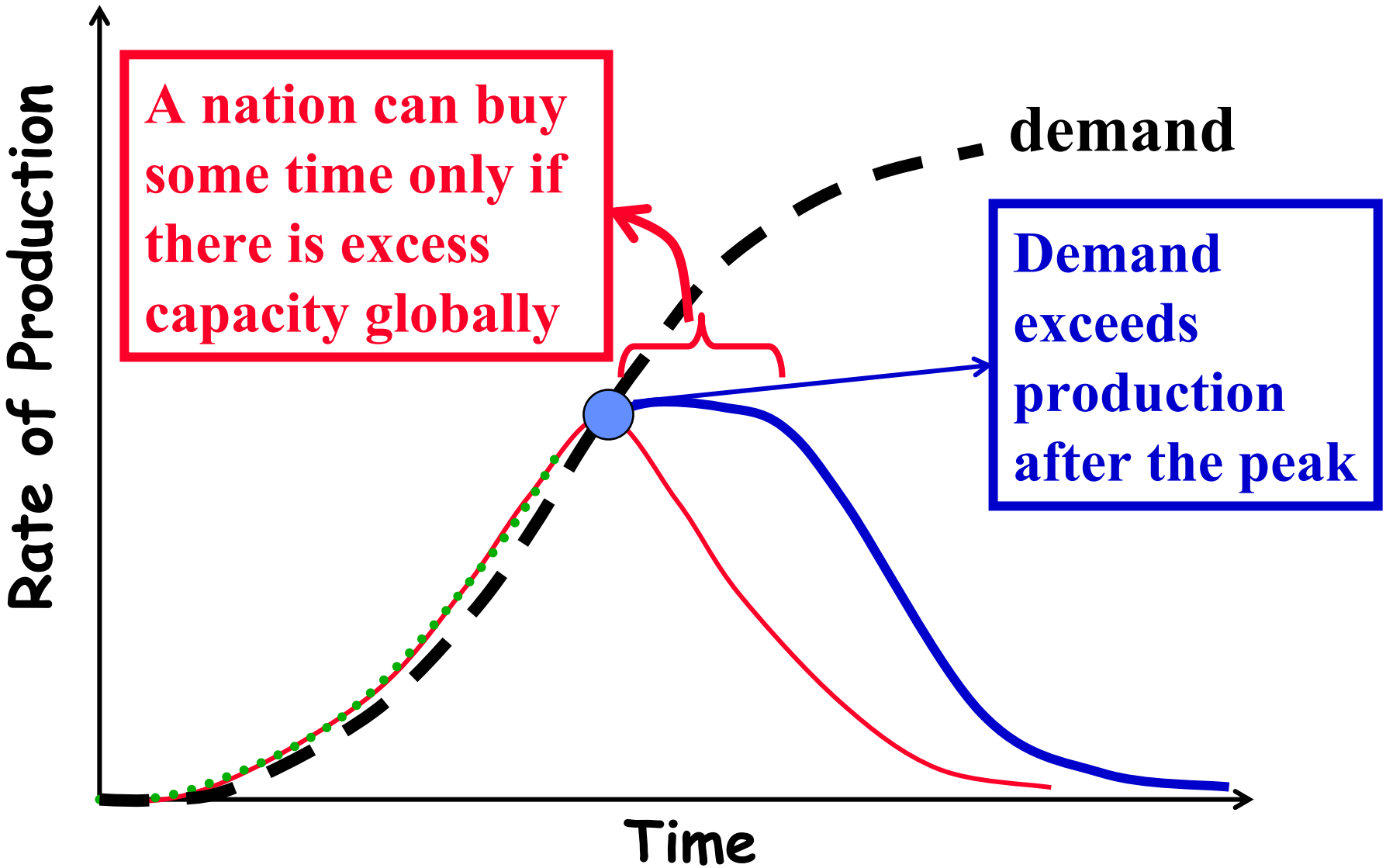
- Animal and plant biomass collected over 100s of millions of years in sedimentary layers
- Biomass in source rock between 7500 (82^{o}C) - 15000 (145^{o}C) feet depth "cracks" into oil. At further depth it gets cooked into methane.
- Source rock must be porous and permeable
- Cap rocks prevent oil from seeping up $\rightarrow$ Fields

Except for South China sea, most regions very well mapped

Recovery of oil/gas is not a mystery



Key issues don't depend on details of the peak

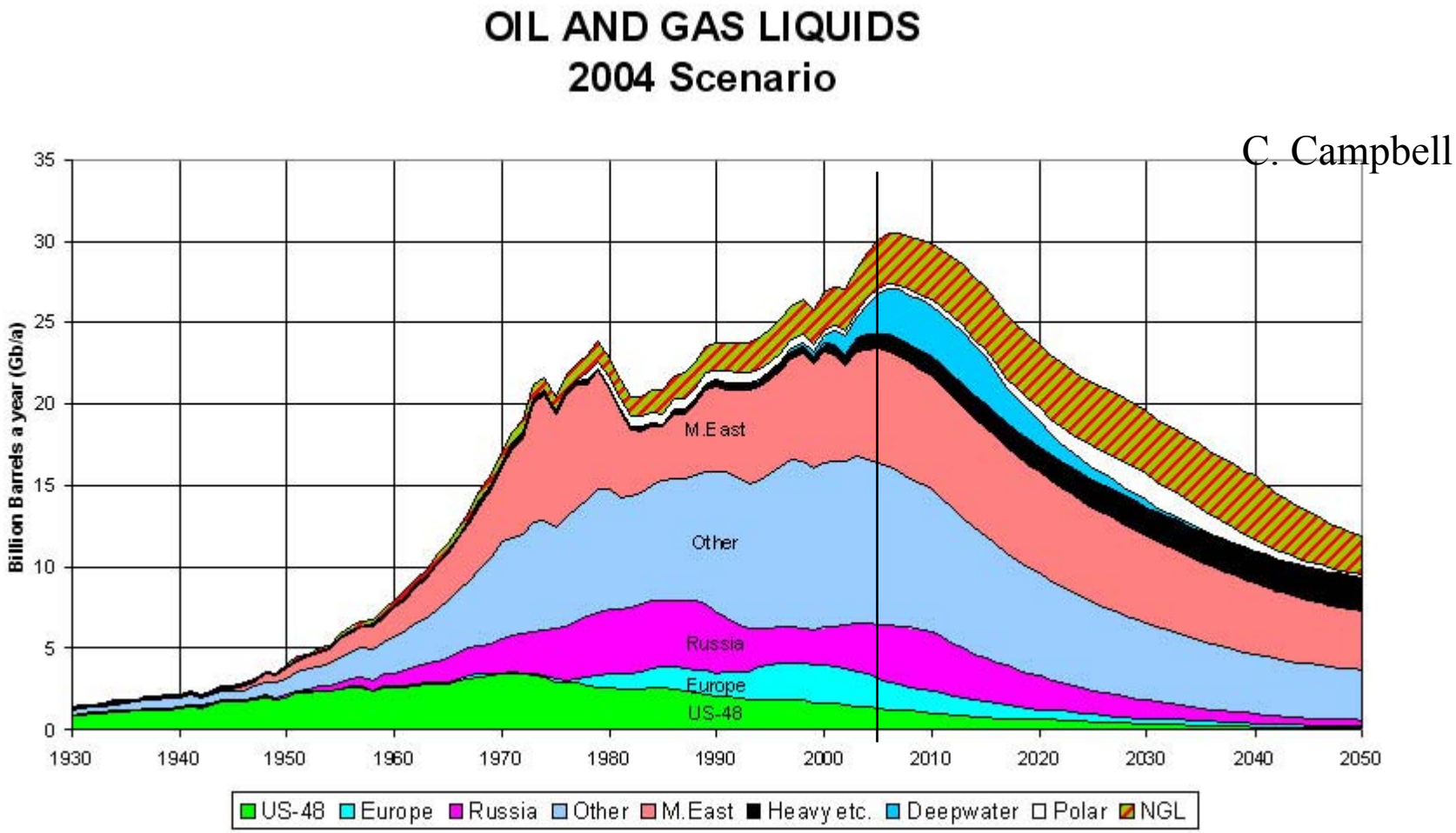


Demand is increasing at ~2%

Many fields/regions are in decline

Supply gap will open after peak

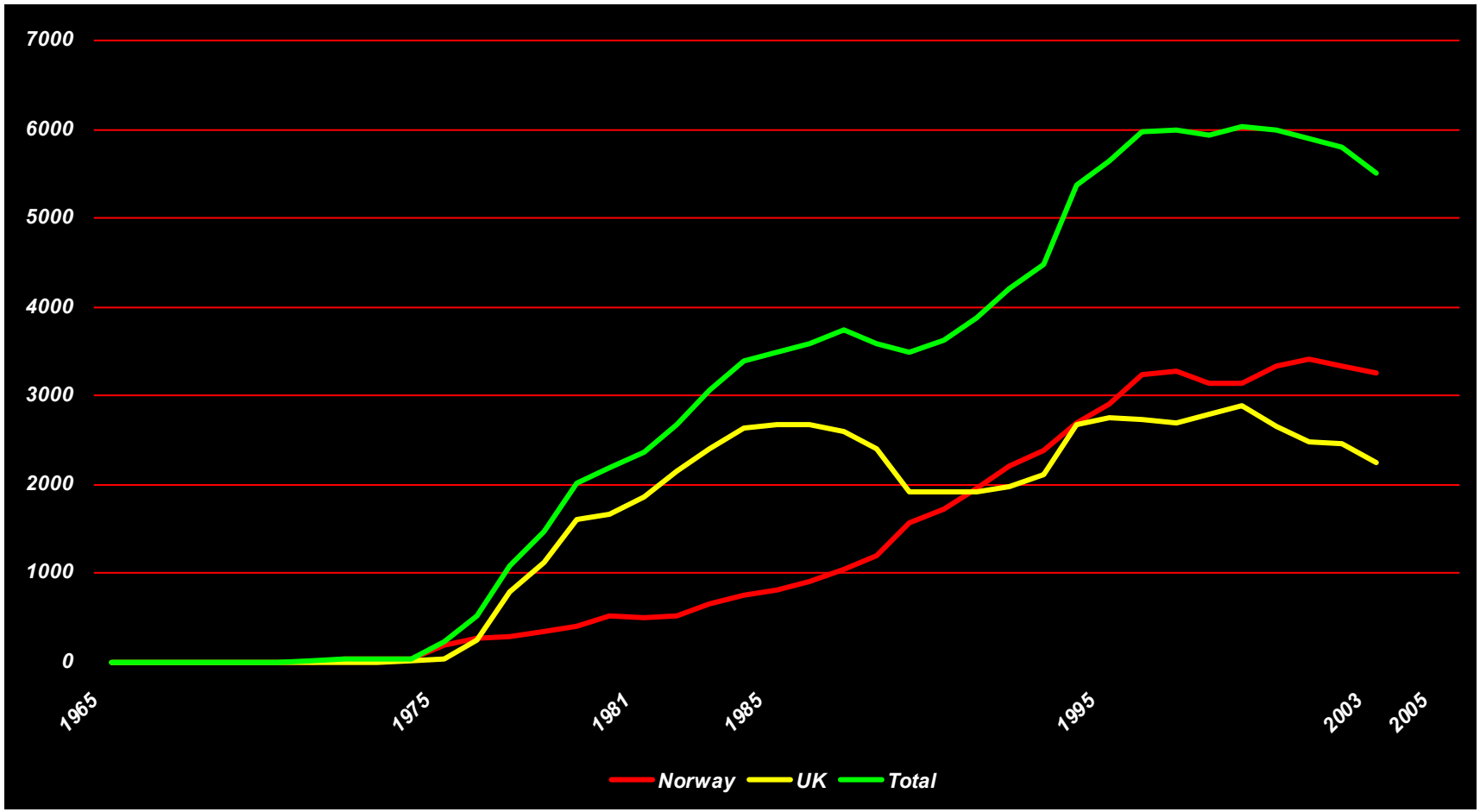
Production decreases rapidly after Hubbert's Peak (2005-09)



A well understood example: North Sea Oil

Peaked in 1999 at 5.94 million bbl/day.

1999-2003: average decline at 2.8% to 5.33 million bbl/day



Source: EIA North Sea summary, BP statistical review 2004

How long will the fuels last?

R/P method

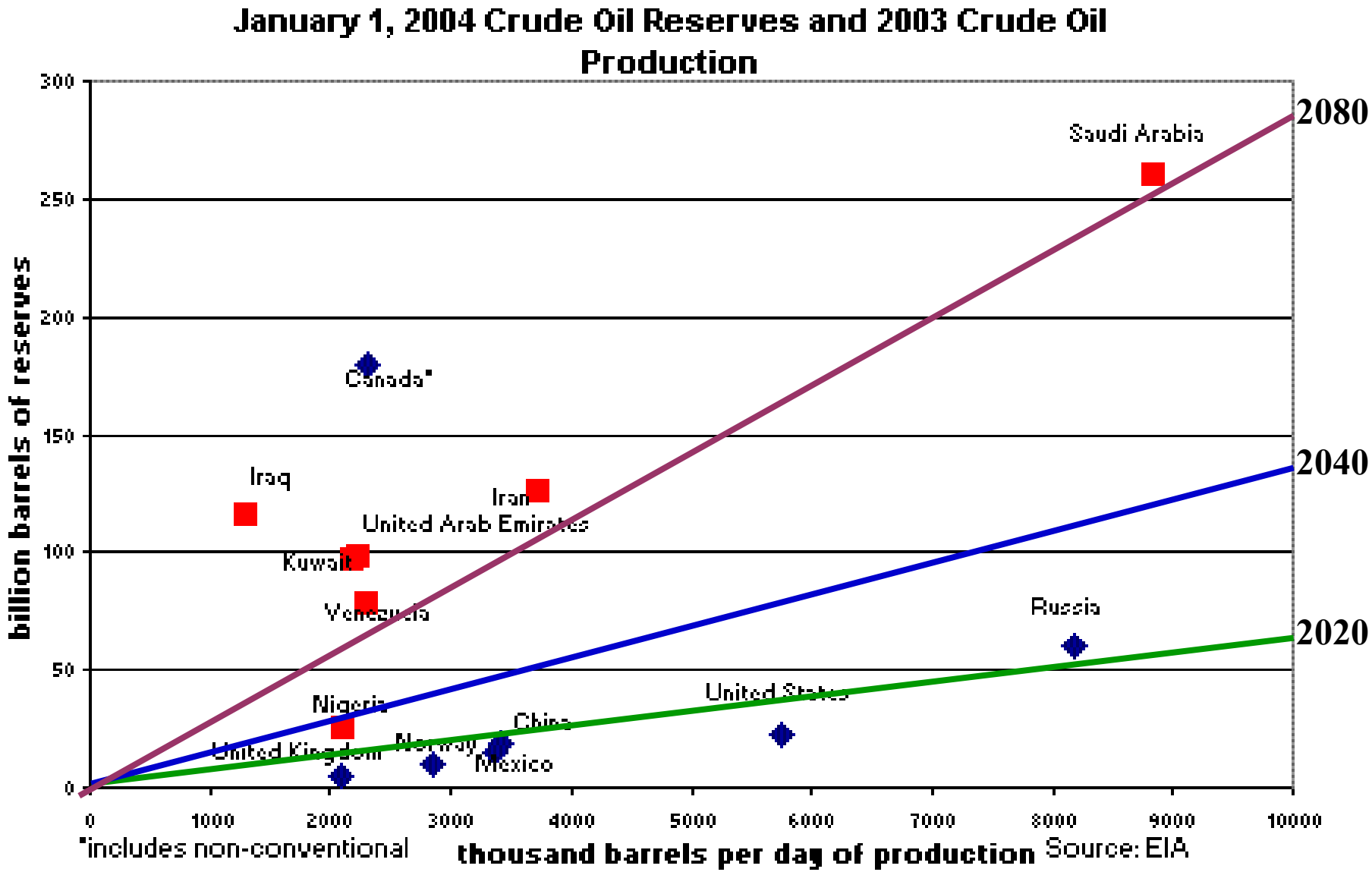
- OIL: 40 years
- GAS: 65 years
- COAL: 200 years
- Uranium: 5-25 years if used to supply all the power (10 Twatts)

Hubbert's Peak

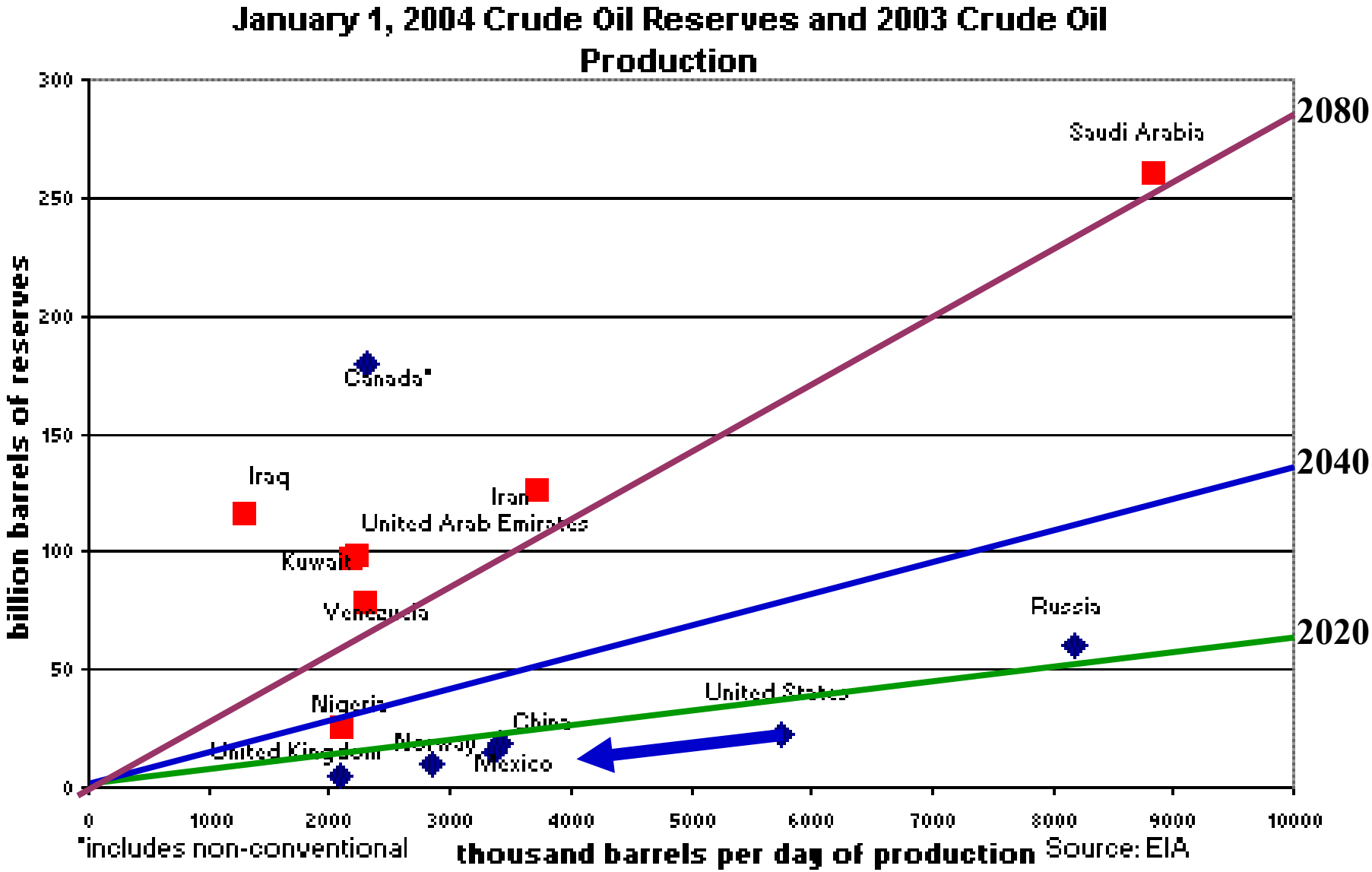
- OIL: Decline after ~2006
- GAS: Decline after ~ 2025
- COAL:
- Uranium:

- **What will be the impact on the environment?**
- **What will be the geopolitical implications?**
- **How to preserve quality of life post oil & gas?**

Reserves/Production timeline



Nations will face decline in production and not an sharp cutoff



Depletion of reserves by 2030

- **OIL: 84%**
- **GAS: 64%**
- **Coal: 25%**

US accounts for ~25% of world consumption

Source: EIA 2003

Tough questions for policy makers

- When will a given fossil fuel end?
- When will production decline?
- What alternate sources can cover the decline?
- What new technologies will come into play?
- What policies and incentives will facilitate a smooth transition? Spur new technologies?
- Can we simultaneously have more energy, less pollution and prevent global climate change?
- What patterns of consumption will we need to change? Forgo?

Examine energy futures from three perspectives

- **National and International security**
- **Economic development**
- **Environment**

NEED for timely action: ***Investment in power systems is recuperated over 40-70 years. It takes 10-15 years to change the system or develop new capacity. Planning and execution has to happen decades before need.***

National and International Security

National and International Security

- Energy is essential for economic development
- Predictable access to energy is key to long term stability, security, prosperity of nations
- Geographical location of energy matters $\Rightarrow$ treaties and cooperation or war between nations

Key Factors in Energy Security

- Domestic production capacity and mix
- Dependence on imports
- Degree of import concentration
- Stocks and strategic petroleum reserves
- World excess capacity
- Geographical distribution & competition
- Improving efficiency

Source: James L. Williams and A.F. Alhajji, www.wtrg.com

OIL

No viable substitute yet for oil in transportation sector

Light oil is mostly alkanes C_nH_{2n+2} and alkenes C_nH_{2n}

Top World Oil Producers (>2 M bpd), 2003**
(OPEC members in red)

	Country	million bpd	Export	Import
1)	*Saudi Arabia*	9.95	8.38	
2)	United States	8.84		11.1
3)	Russia	8.44	5.81	
4)	*Iran*	3.87	2.48	
5)	Mexico	3.79	1.74	
6)	China	3.54		2.00
7)	Norway	3.27	3.02	
8)	Canada	3.11	2.1	
9)	*United Arab Emirates*	2.66	2.29	
10)	*Venezuela*	2.58	2.23	
11)	United Kingdom	2.39	0.61	
12)	*Kuwait*	2.32	2.00	
13)	*Nigeria*	2.25	1.93	

Source: EIA, BP

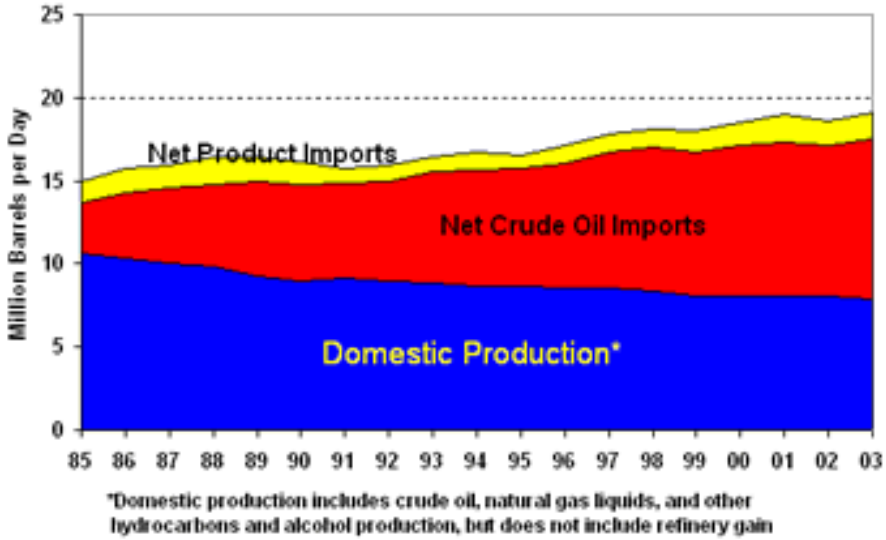
**Total Oil Production includes crude oil, natural gas liquids, condensate, refinery gain, and other liquids

2002 rank	Country	2002 proved OIL reserves (billion barrels)
1.	Saudi Arabia	261.7
2.	Iraq	115.0
3.	Iran	99.1
4.	Kuwait	98.9
5.	United Arab Emirates	62.8
6.	Russia	53.9
7.	Venezuela	50.2
8.	Libya	30.0
	Nigeria	30.0
10.	China	29.5
11.	USA	22 (2004 end)

- Middle East
- Exporters
- Importers

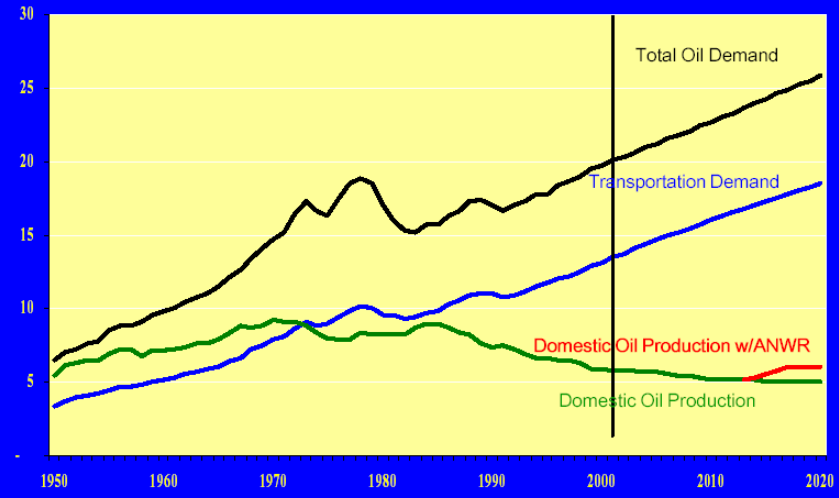
Source: EIA, BP

U.S. Oil Production and Imports



*Domestic production includes crude oil, natural gas liquids, and other hydrocarbons and alcohol production, but does not include refinery gain

US Oil Consumption (million barrels per day)



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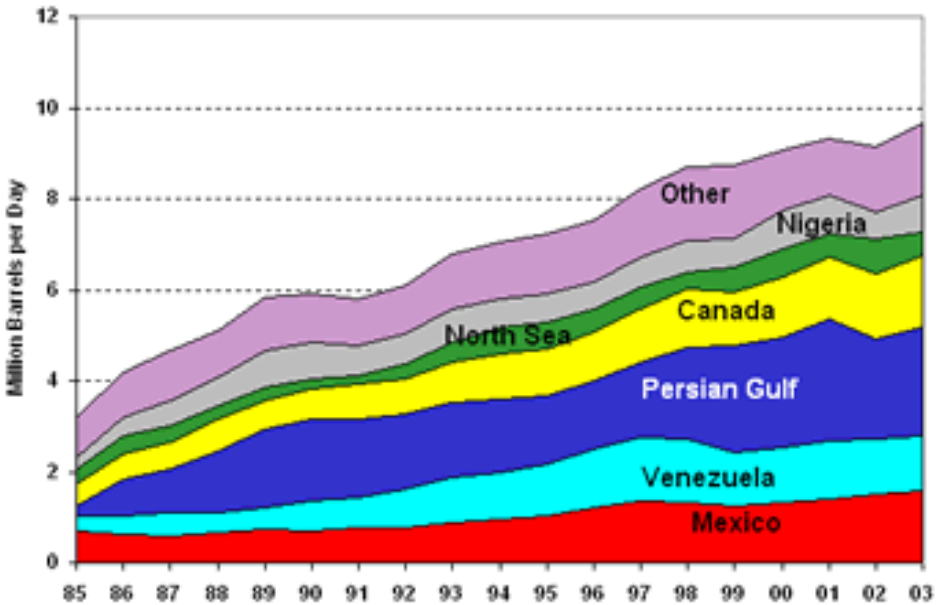
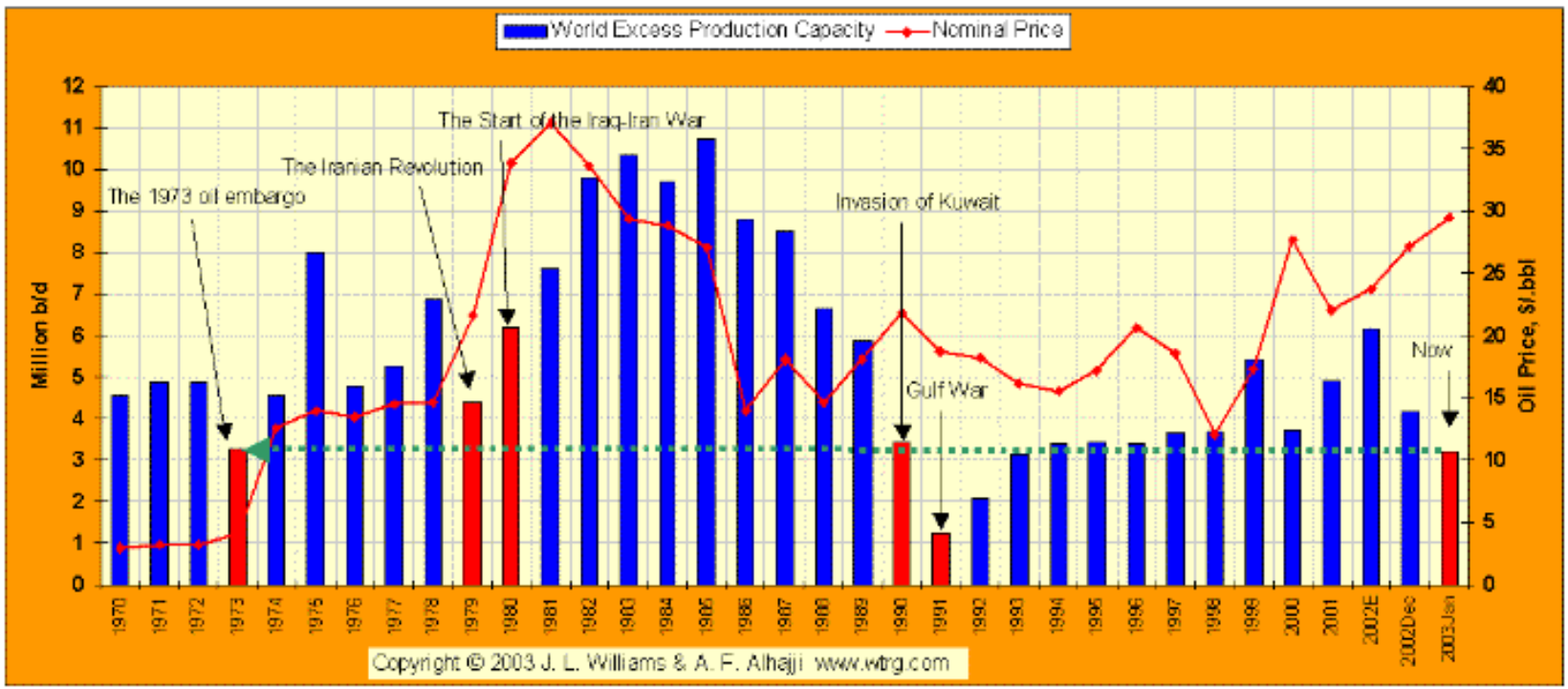
U.S. Crude Oil Imports by Source



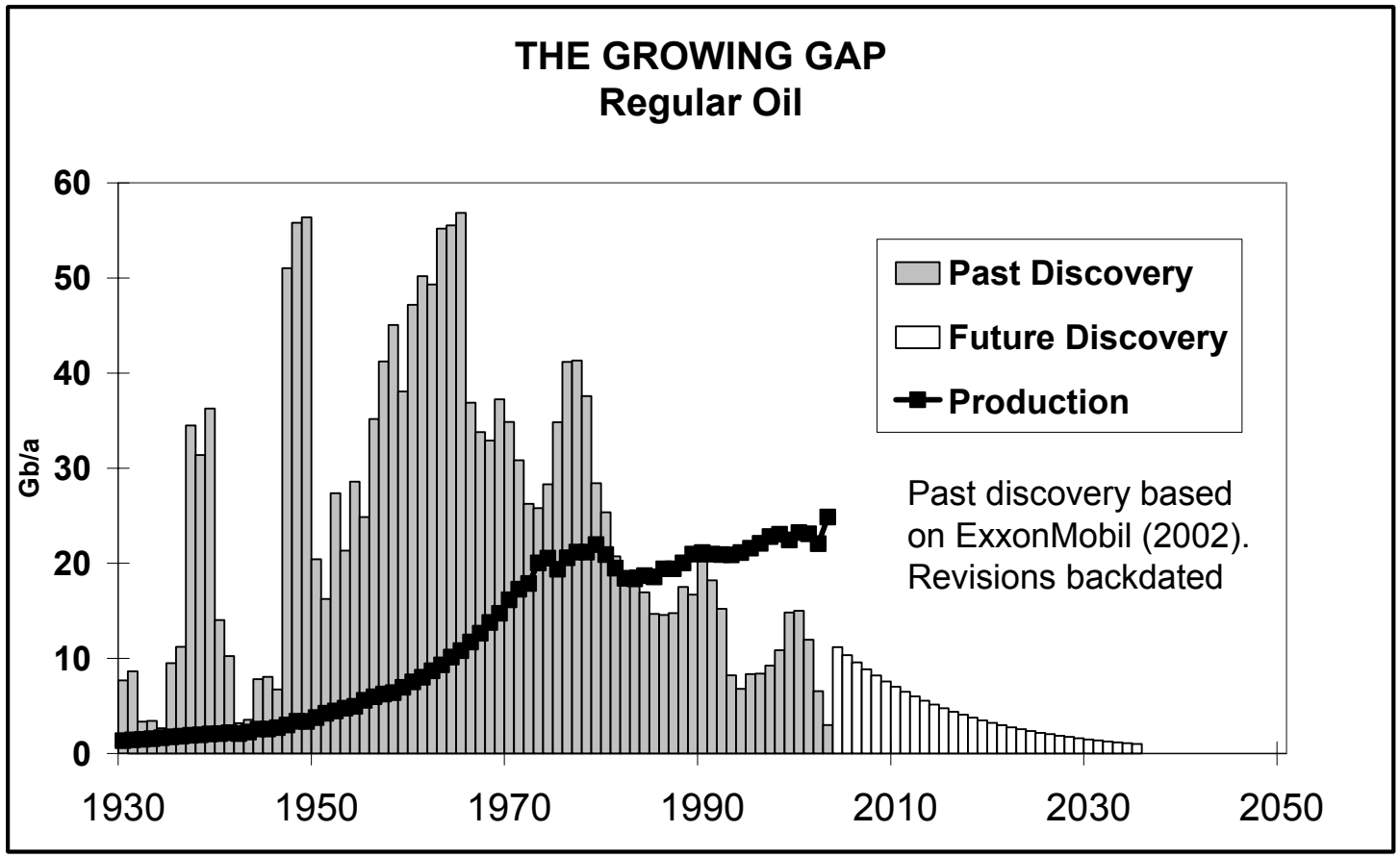
Middle East:	2.5 M barrels
Africa:	2.0 M barrels
Venezuela:	1.5 M barrels
Canada	1.8 M barrels
Mexico:	1.4 M barrels
North Sea:	0.9 M barrels
Far East:	0.4 M barrels
Soviet Union:	0.1 M barrels

Production, Discovery, Excess

- Many of the larger oil fields are in decline
- Discovery is of smaller fields and in less accessible areas
- World consumption is increasing at ~2%
- In early Sept. 2004, excess world oil production capacity fell to 0.5-1.0 M b/d, all of which was in Saudi Arabia.



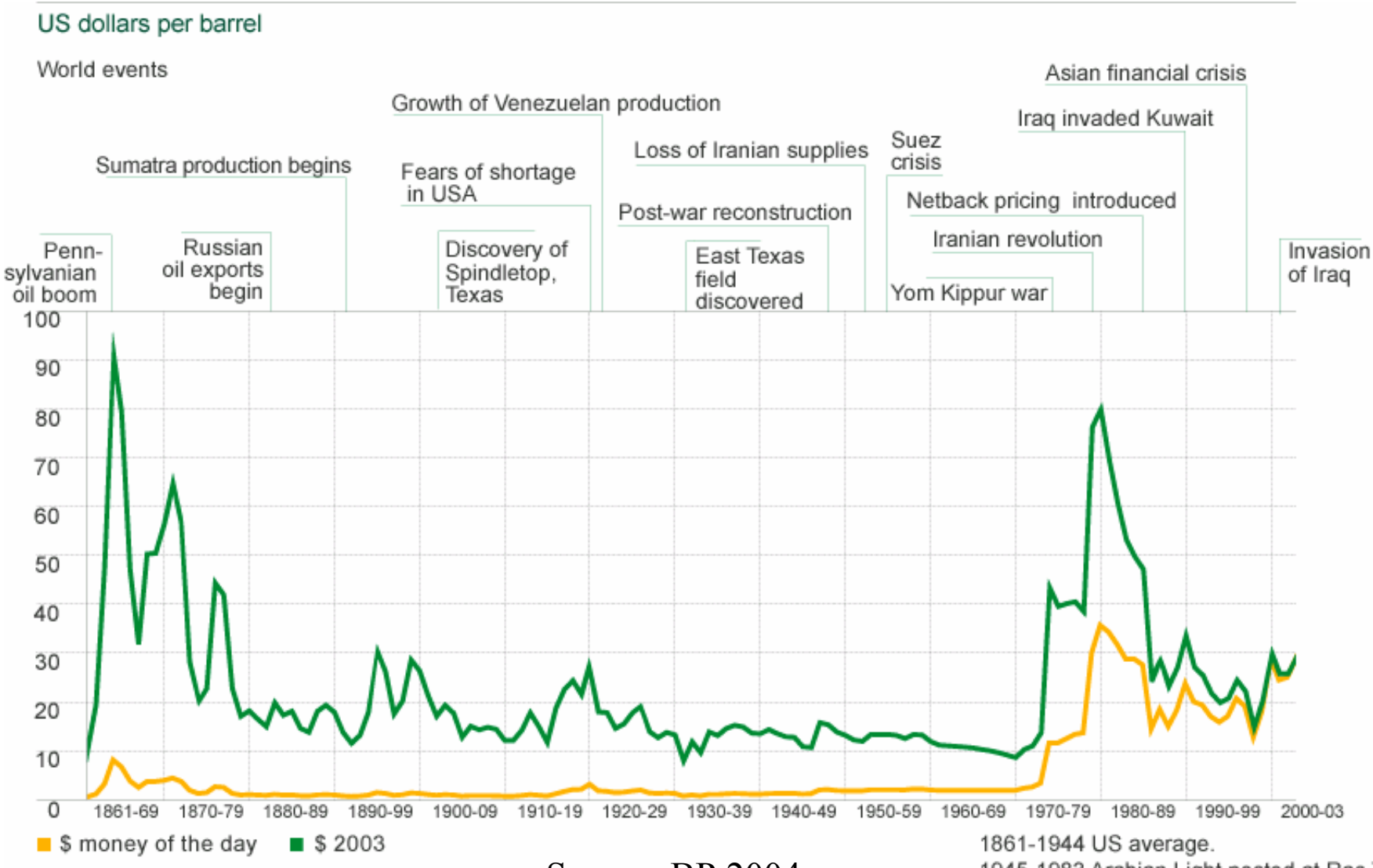
Production, Discovery, Excess



C. Campbell

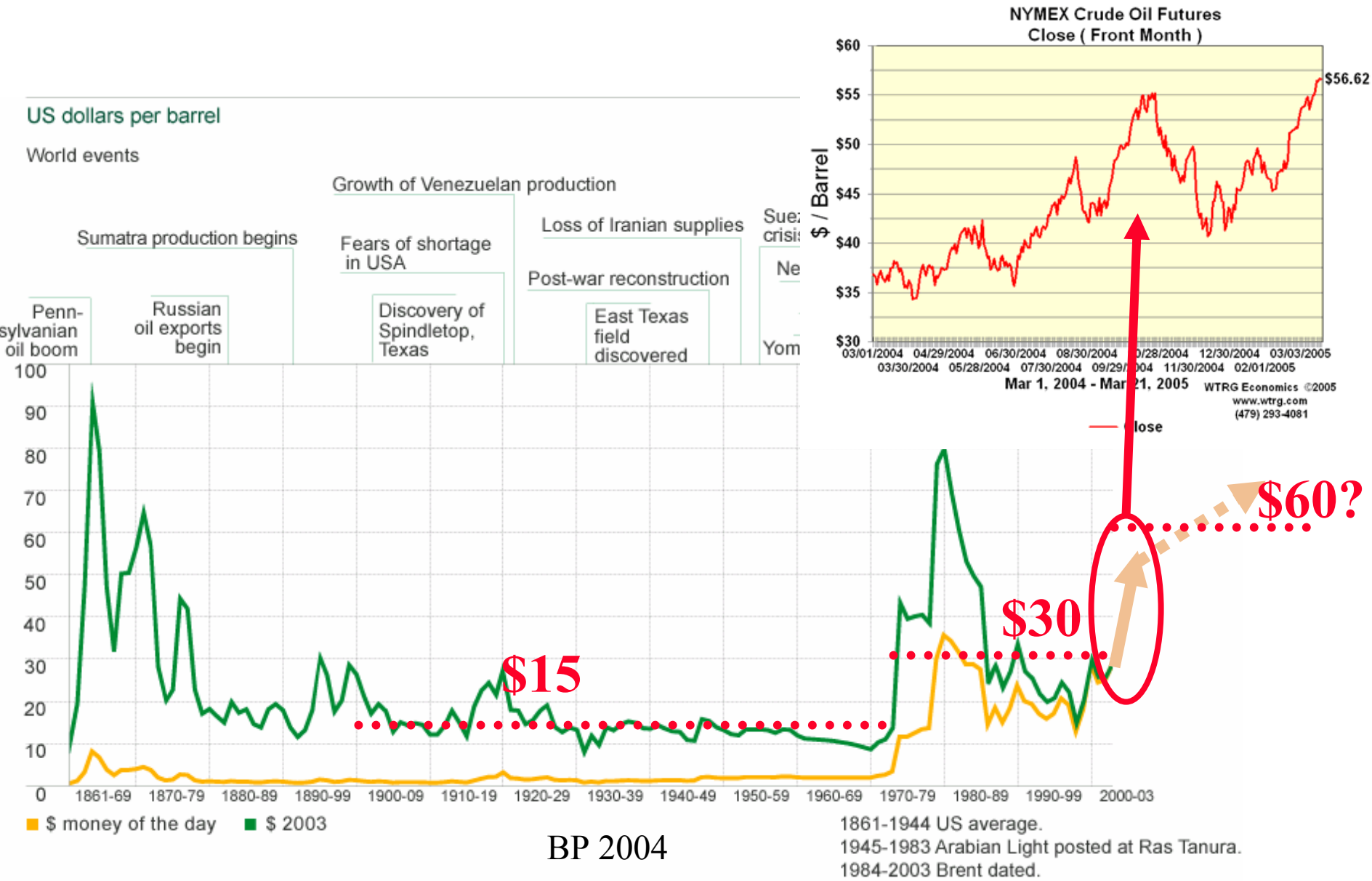
The price of all oil is decided by the last barrel sold

Crude oil prices since 1861



Source: BP 2004

Increased volatility and high prices post 2004?



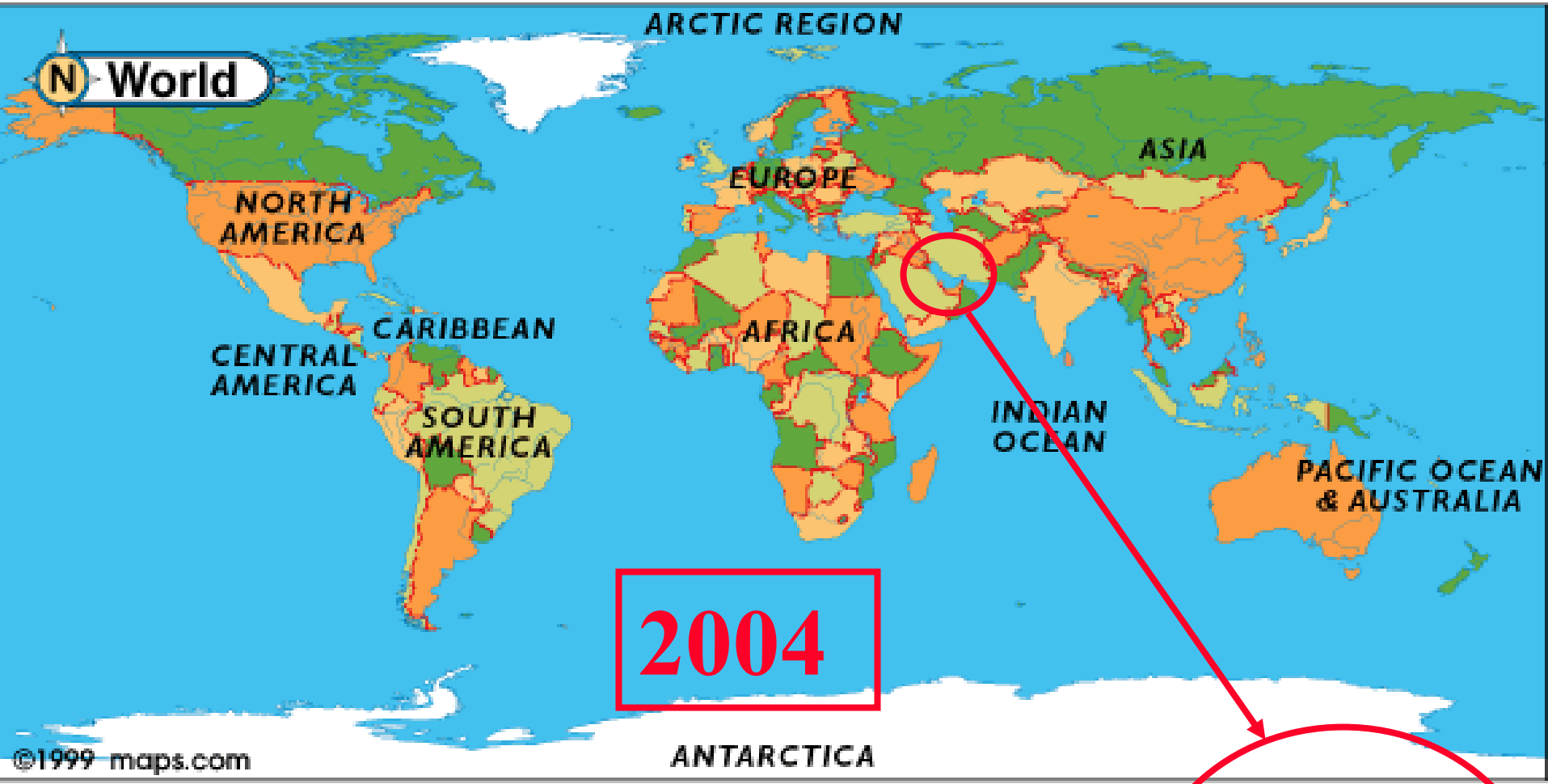
BP 2004

Natural Gas

- Methane CH_4
- Ethane C_2H_6
- Propane C_3H_8
- Butane C_4H_{10}

2002 rank	Country	2002 proved GAS reserves (trillion cubic feet)
1.	Russia	1,700.0
2.	Iran	939.4
3.	Qatar	757.7
4.	Saudi Arabia	228.2
5.	United Arab Emirates	204.1
6.	United States	183.5 @ 22Tcf /per year
7.	Algeria	175.0
8.	Nigeria	159.0
9.	Venezuela	149.2
10.	Iraq	112.6

Geographical distribution of oil, gas, and coal reserves matters and will matter more with time as reserves dwindle



USA 11,6,1

China 10,-,3

EU -, -, 6

Russia 6,1,2

India -, -, 4

Persian Gulf

OIL 1,2,3 4,5

GAS 2,3,4, 5,10

No Coal

rg@lanl.gov

http://t8web.lanl.gov/people/rajan/

USA -,-,1

China -,-,3

EU -, -, 6

Russia -,1,2

India -, -, 4

Persian Gulf

OIL 1,2,3 4,5

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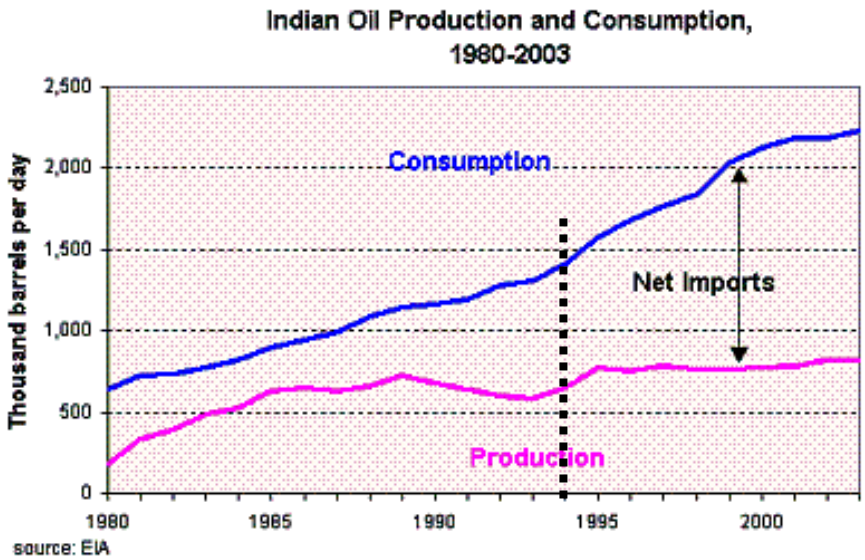
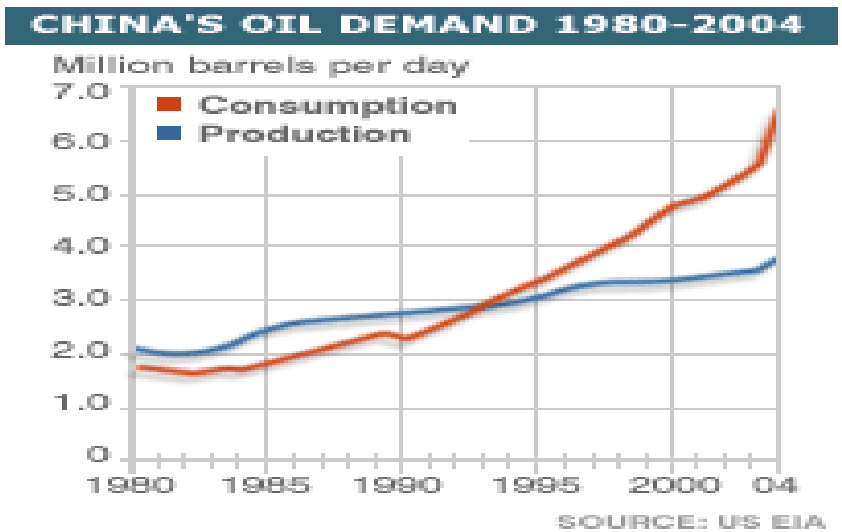
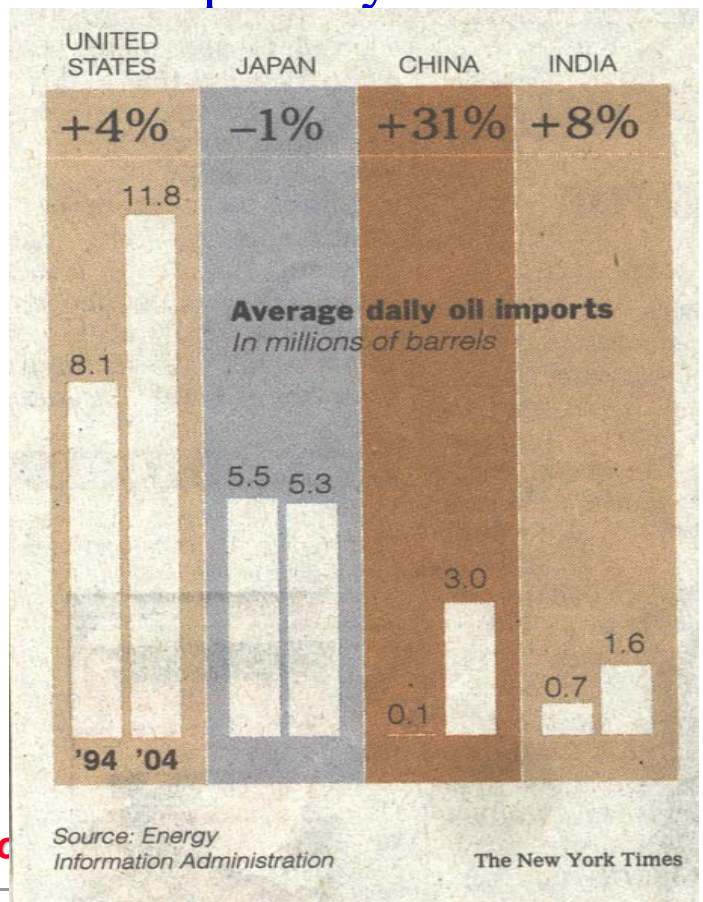
Increasing competition for oil and gas





China and India are making deals with Iran, Sudan, …

Chinese imports jumped by ~1Mbo/per day in 2004!



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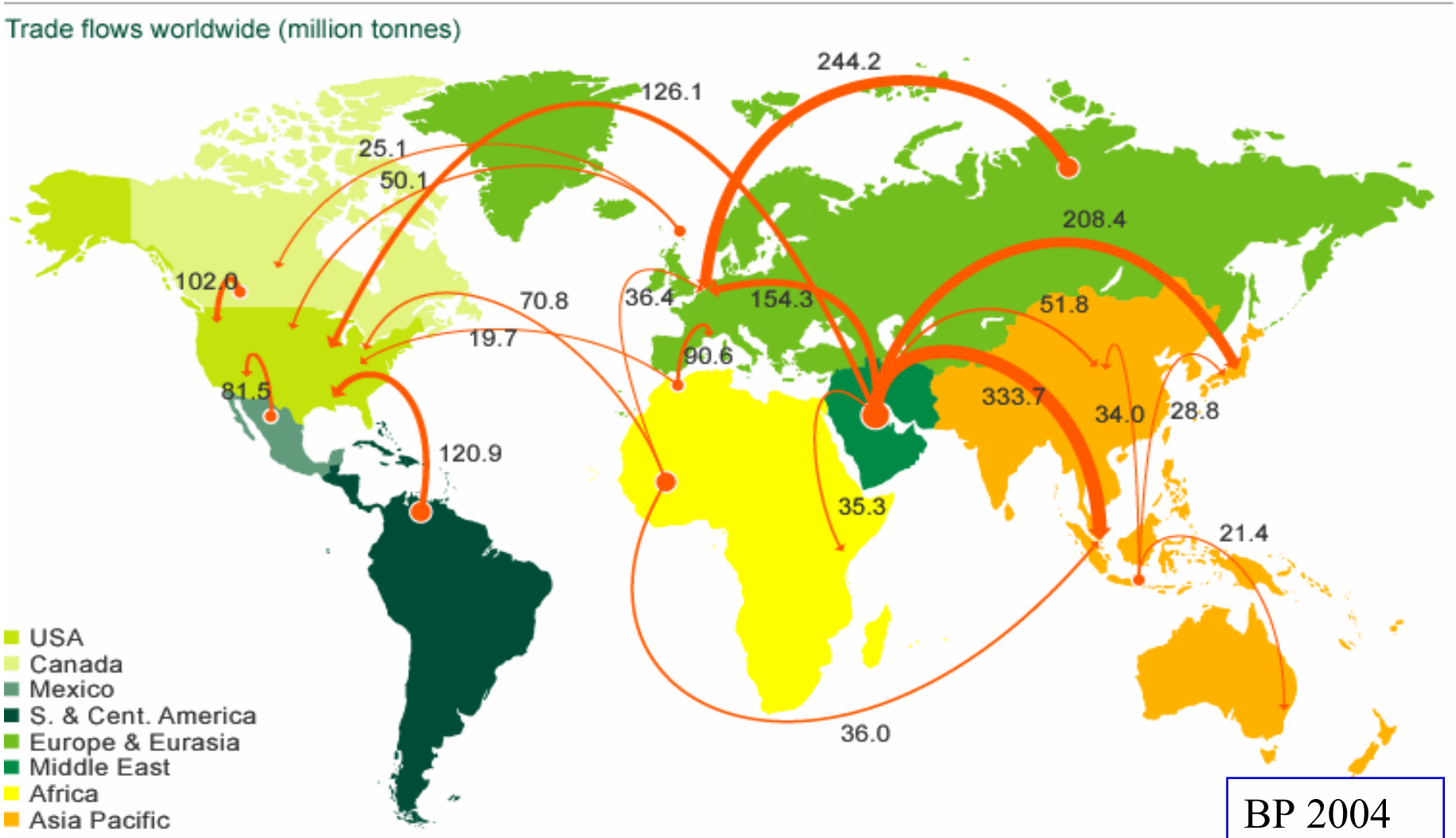
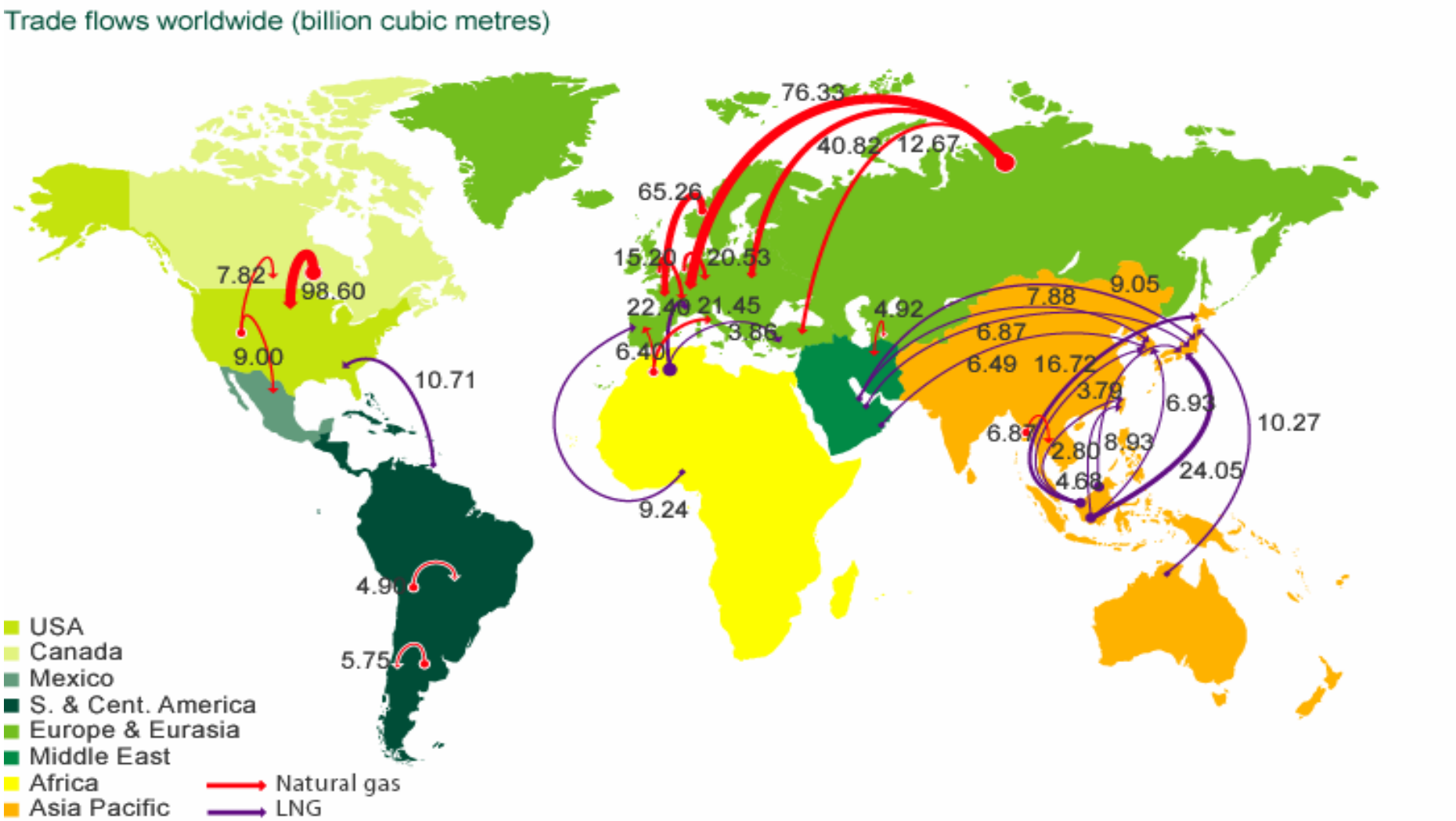
http://t8web.lanl.gov/pec

Major oil trade movements

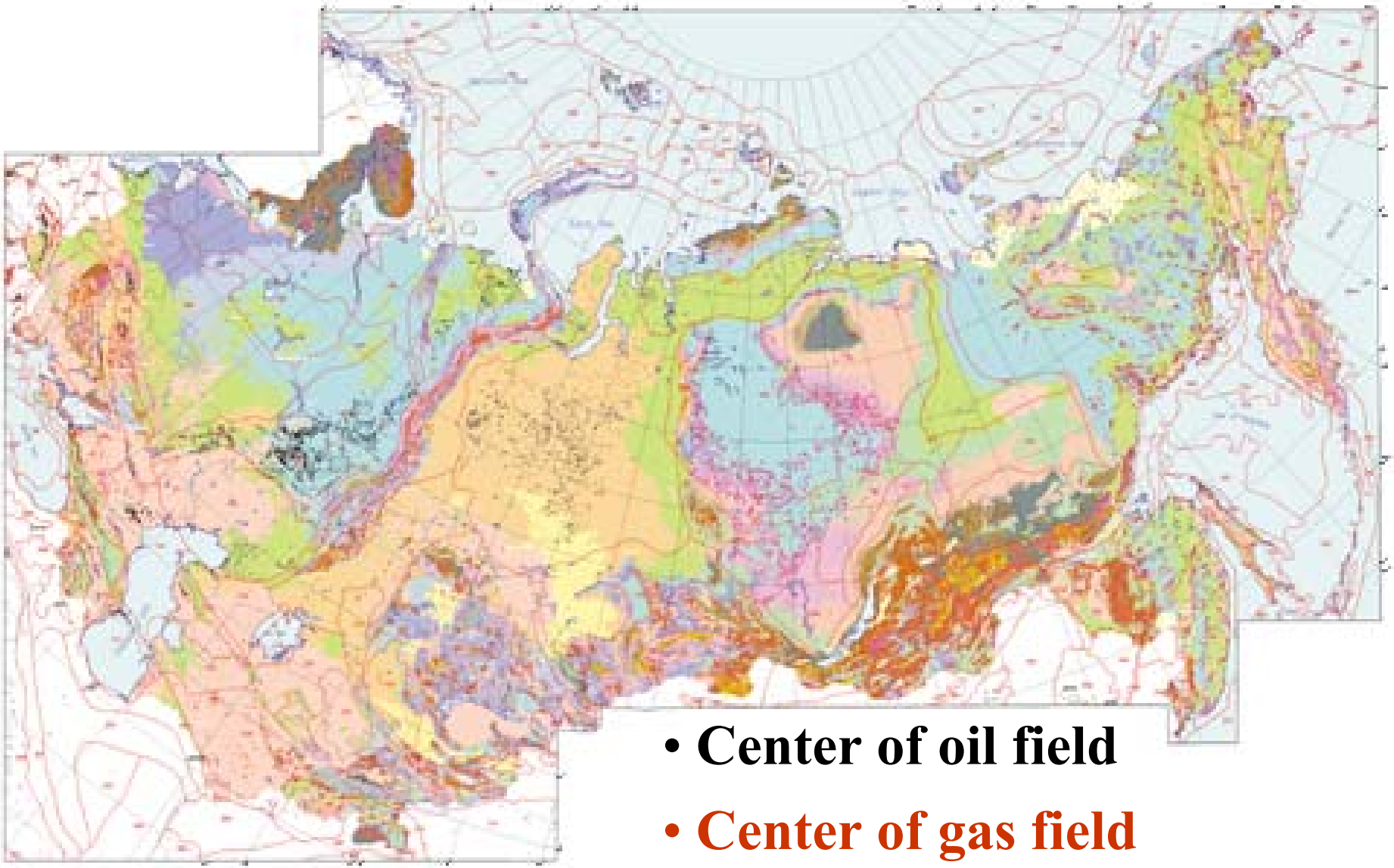


BP 2004

Major natural gas trade movements



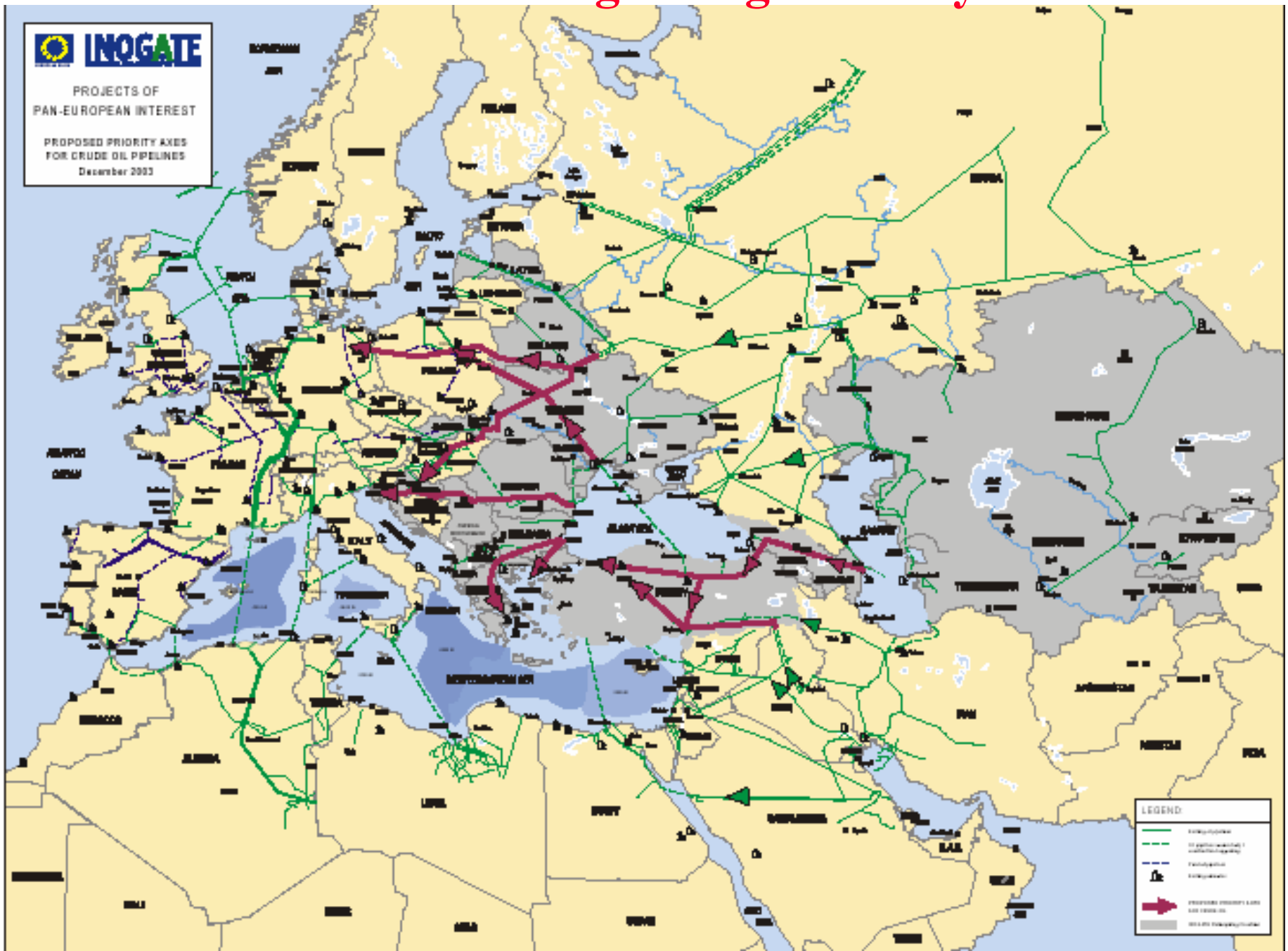
Where will Russian oil and gas go?



- Center of oil field
- Center of gas field

http://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470E/fsumapG.html

Which countries will get oil/gas in 10 years



The natural destination for Persian gulf, Caspian Sea and Russian oil and gas is EURASIA

But the US needs them too!

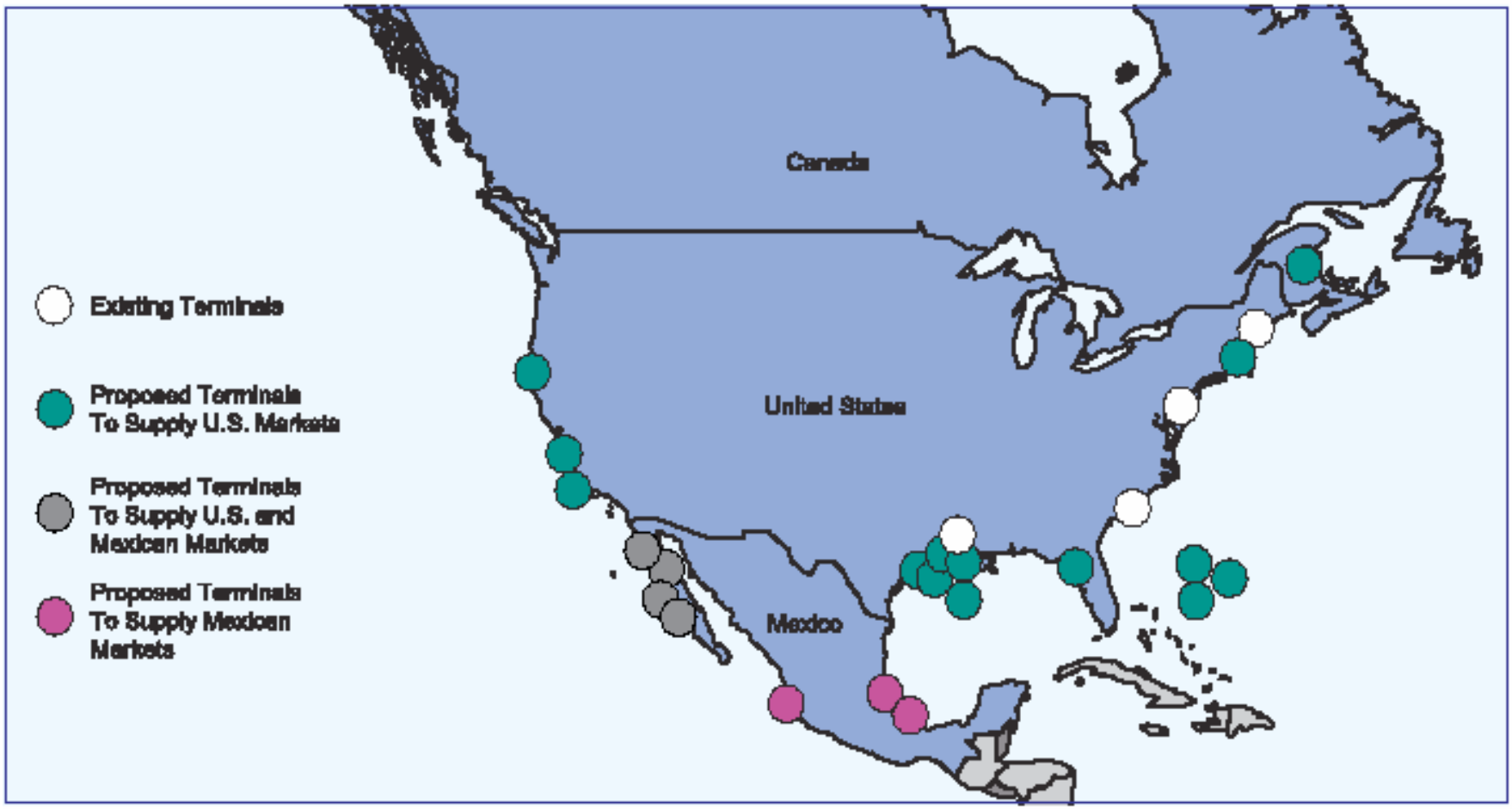
What role will pipeline, tanker, refining capacity play?

Without the infrastructure to liquefy Natural Gas (LNG) and ship it, the US cannot access global gas reserves

At current rate of use (22 Tcf in 2003) the US reserves ~(200+200) Tcf will last only 20 years by the R/P criteria

New LNG facilities start operating in 2008

Figure 42. Existing U.S. LNG Terminals and New Terminals Planned in North America



Source: Energy Information Administration.

IEO 2004

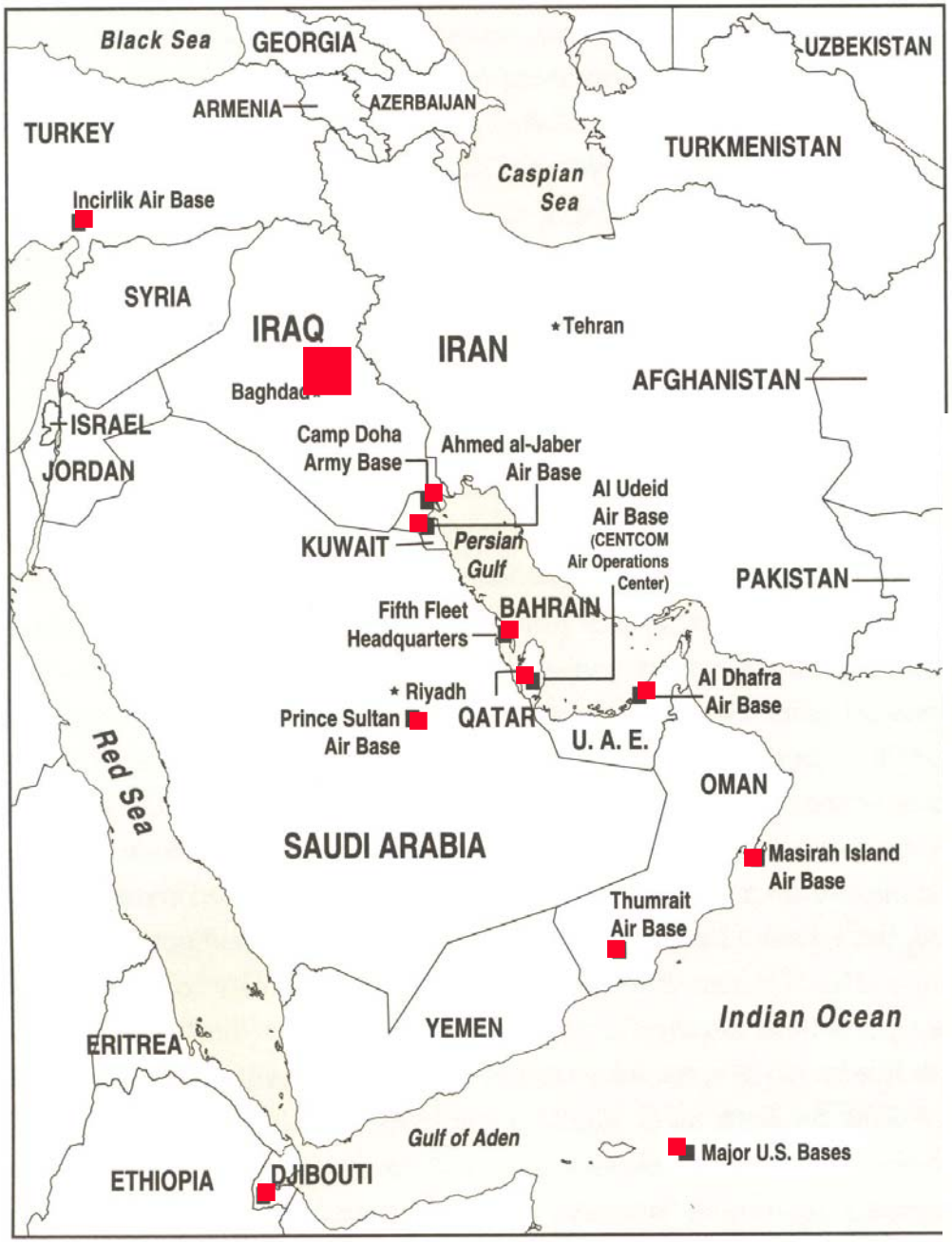
This global oil and gas situation has been anticipated by the US and it has guided its policies since WWII

Oil: key driver of foreign policy

- 1945
  - F. Roosevelt and King Abdel Aziz “oil for security”
- 1947: Truman Doctrine
  - Stop the spread of communism (Greece, Turkey, Iran)
- 1957: Eisenhower Doctrine
  - Protect friendly interests
- 1969: Nixon
  - Protect interests through surrogate friendly rulers
- 1980: Carter Doctrine
  - To protect Saudi Arabia and the free flow of oil from the Persian Gulf
- 1983: Establishment of Central Command
  - Protecting the free flow of oil from the Middle East and Central Asia

US bases in Middle East and Central Asia.

A very successful but costly military investment



What is the true cost of USA's thirst for oil?

- Should we continue to demand more?
- Use our military to guarantee supplies?
- Or use innovation (R&D) to reduce dependence on imported oil and gas and preserve reserves in our protected lands for the future?
- Or burn more coal?

COAL

- Mostly carbon
  - composition varies between C and CH
  - produces most CO_2 on burning
- Contains many pollutants
  - Sulfur $\rightarrow SO_2 \rightarrow H_2SO_3$
  - NO_x
  - Mercury
  - Arsenic

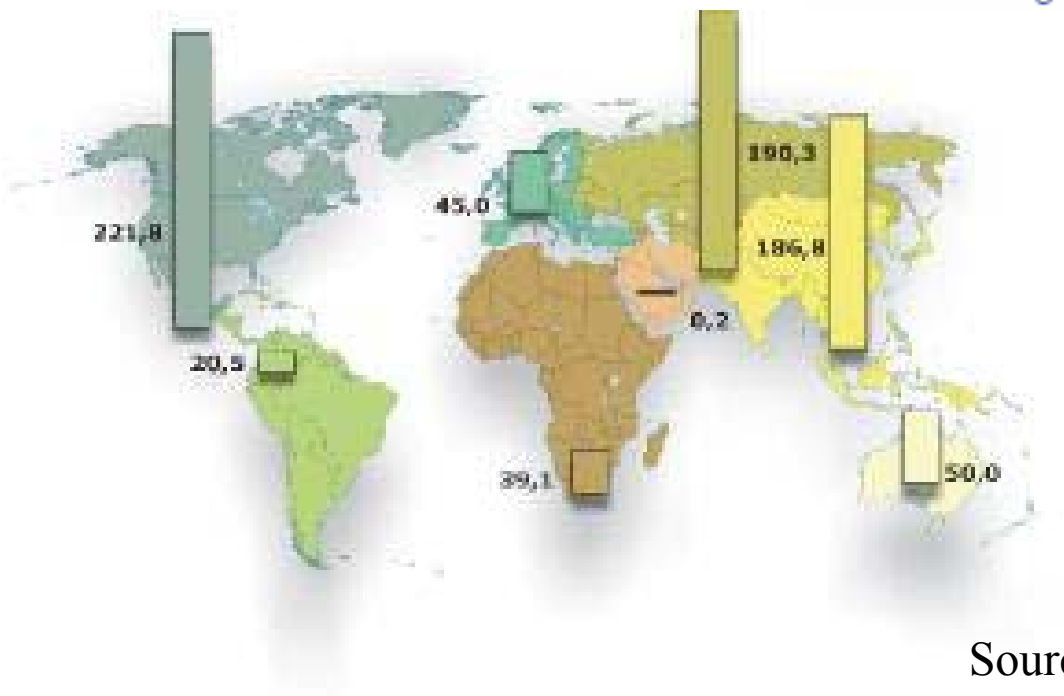
COAL is abundant

Based on 2001 production figures, global coal reserves will last about

- **207 years for hard coal**
- **198 years for soft brown coal**

We can lead the world by innovating clean coal technology for generating electricity

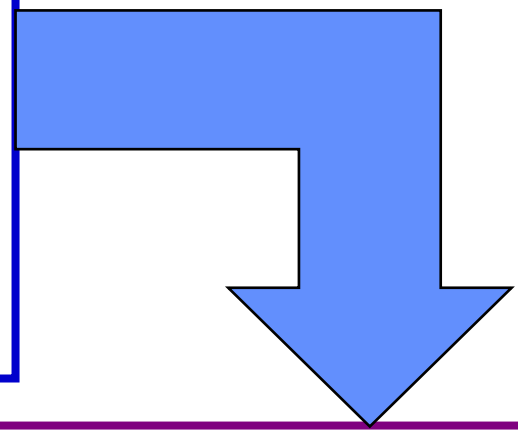
90% of global coal reserves are in 10 countries



Source: International Energy Outlook 2004

Clean Coal Initiatives

- Integrated Gasification Combined Cycle (IGCC)
- FutureGen
- Vision 21



- **Multiple feedstock**
- **Higher efficiency (CC)**
- **Multiple products (modular)**
- **Zero CO2 and polluting emissions**

Clean coal technology has yet to be implemented

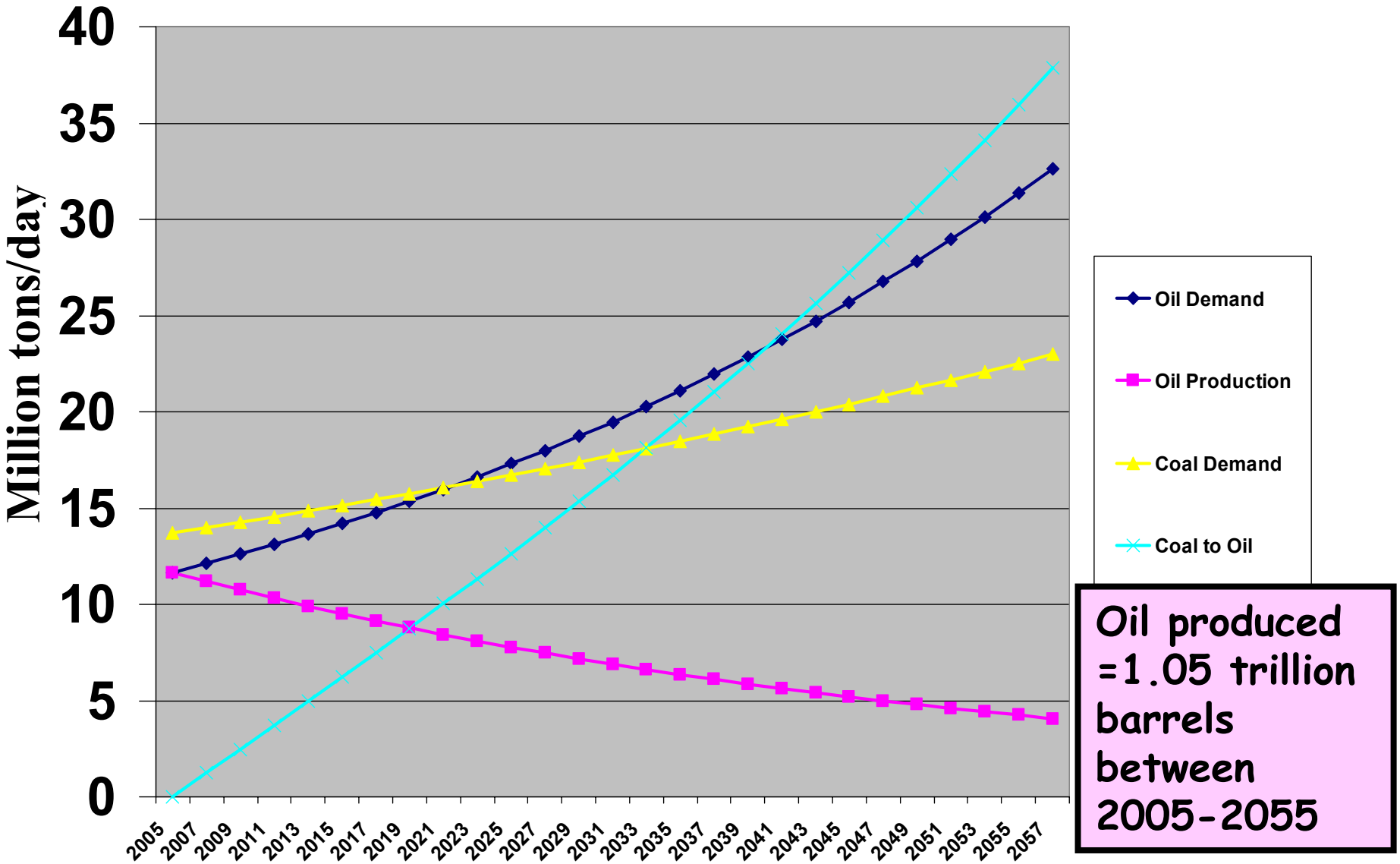
What happens if conventional oil peaks in 2005, demand continues, and coal is used to cover the shortage?

Oil demand growth 2% /per year

coal demand growth 1%

Oil production decline 2%

coal to oil to cover shortfall



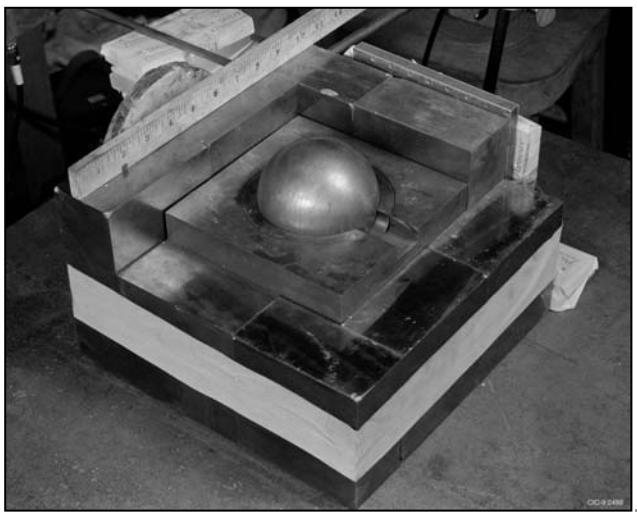
Oil produced =1.05 trillion barrels between 2005-2055

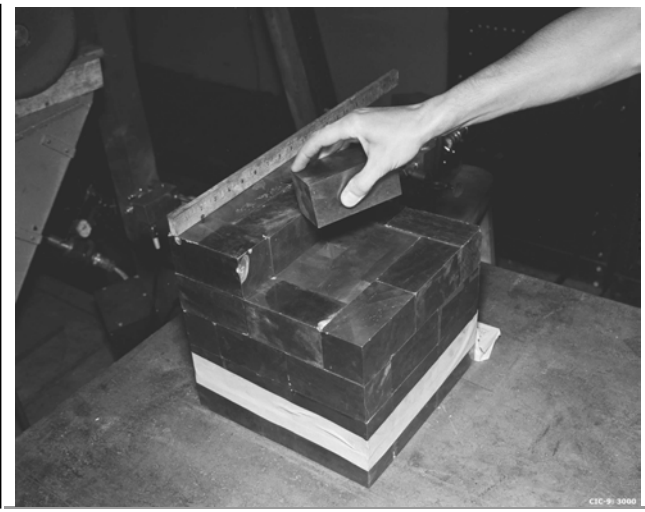
The magnitudes are staggering. Without clean coal we have a huge environmental problem

Pollution and global climate change

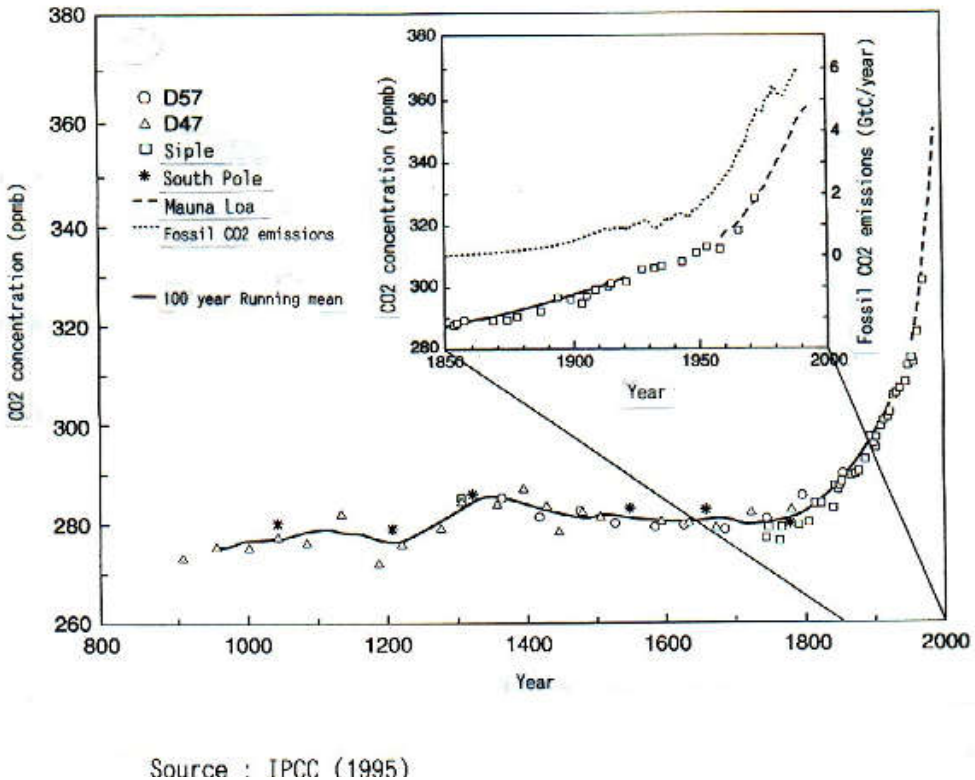
Energy and Environment

Climate change is the largest and costliest uncontrolled experiment being done

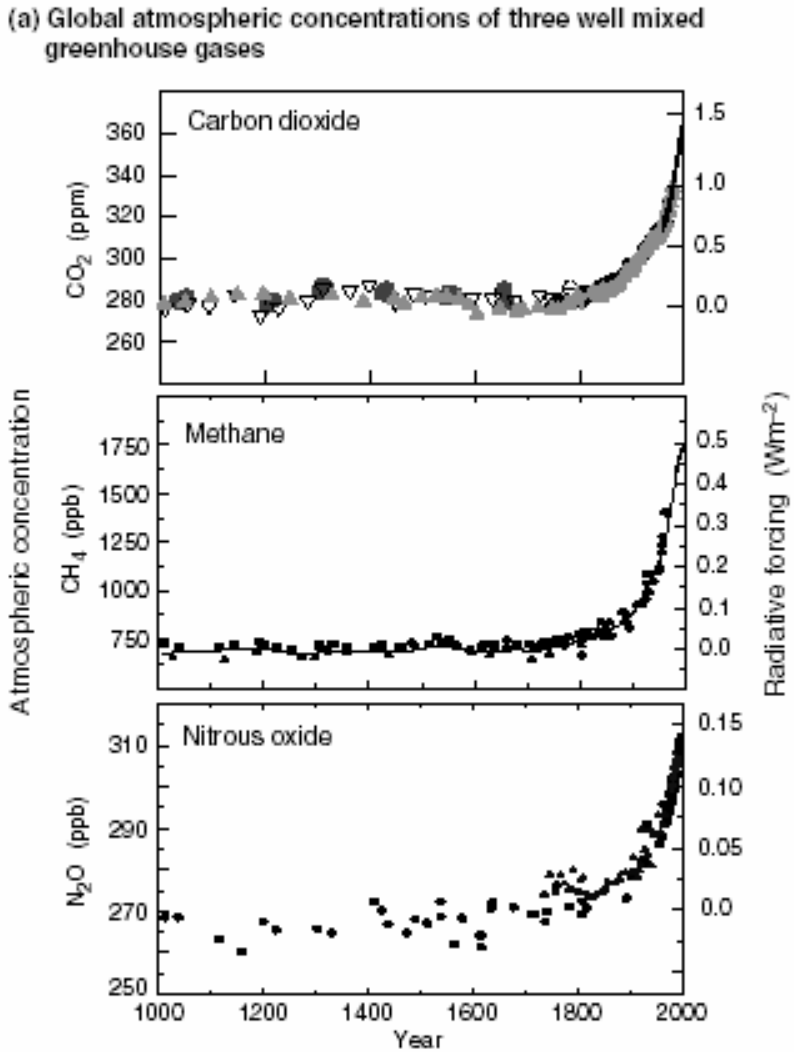




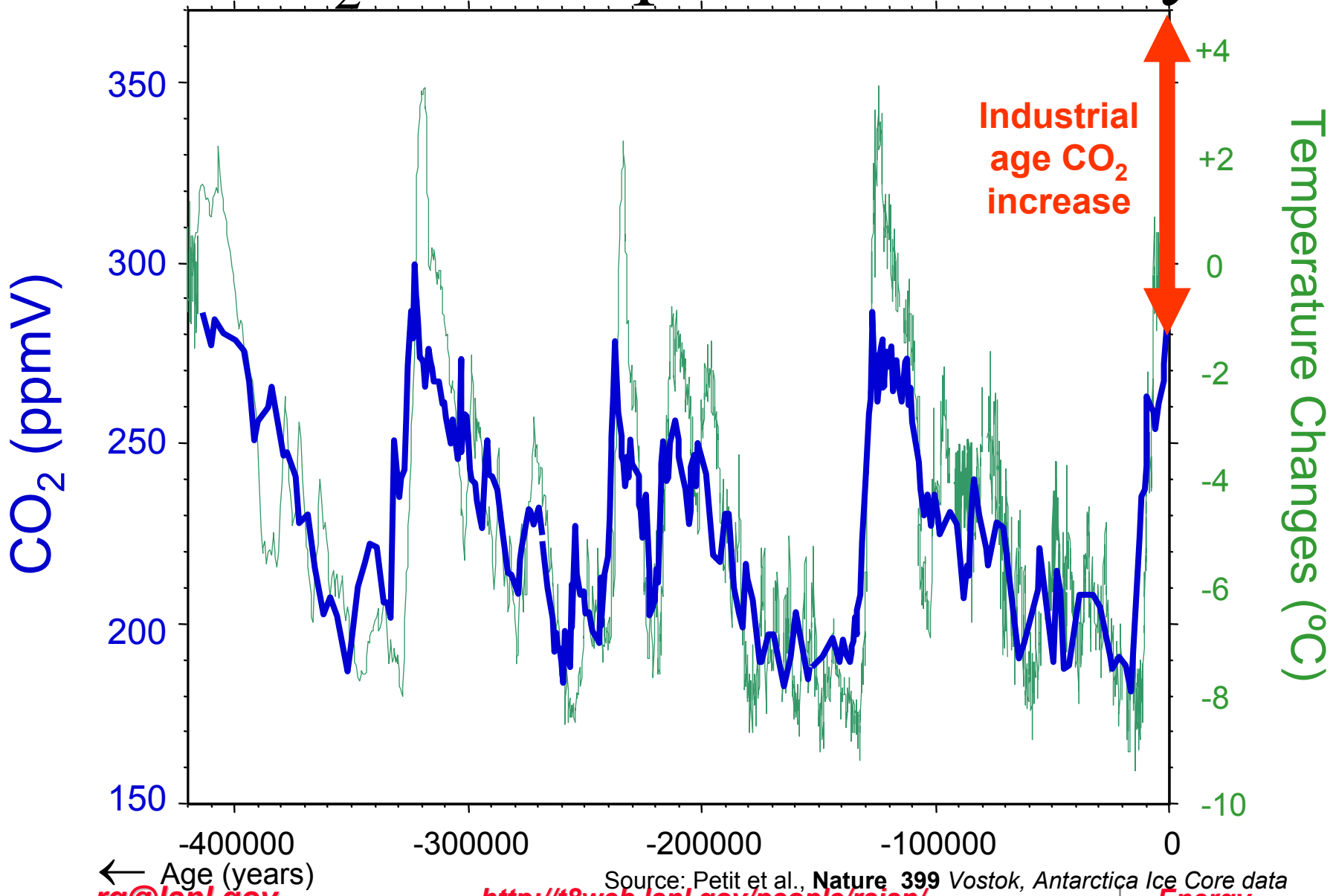
CO_2 concentrations over the last 1000 years. The rise since 1850 parallels the increase in emissions from fossil fuels



Source : IPCC (1995)



CO_2 & Temperature History



Source: Petit et al., **Nature 399** *Vostok, Antarctica Ice Core data*

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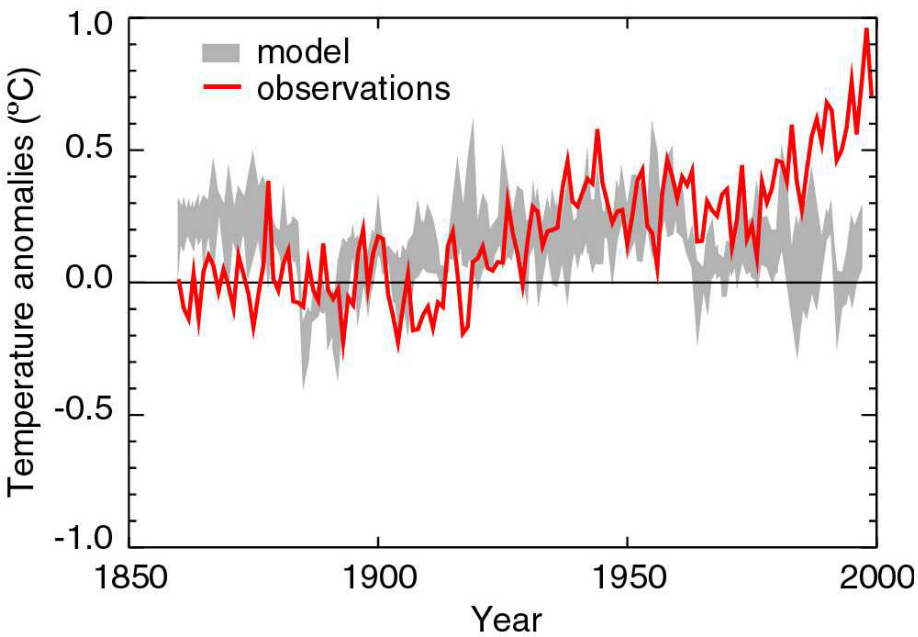
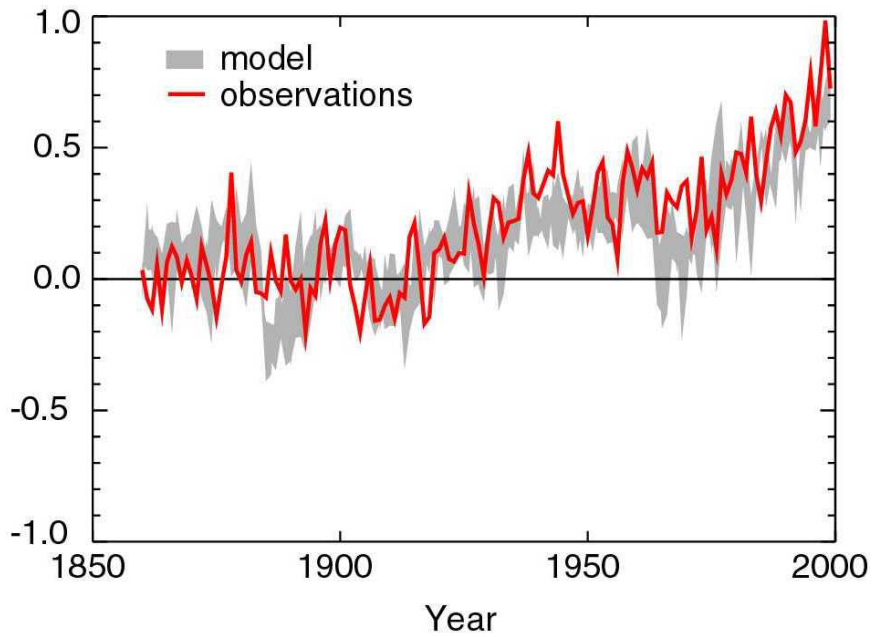
Attribution



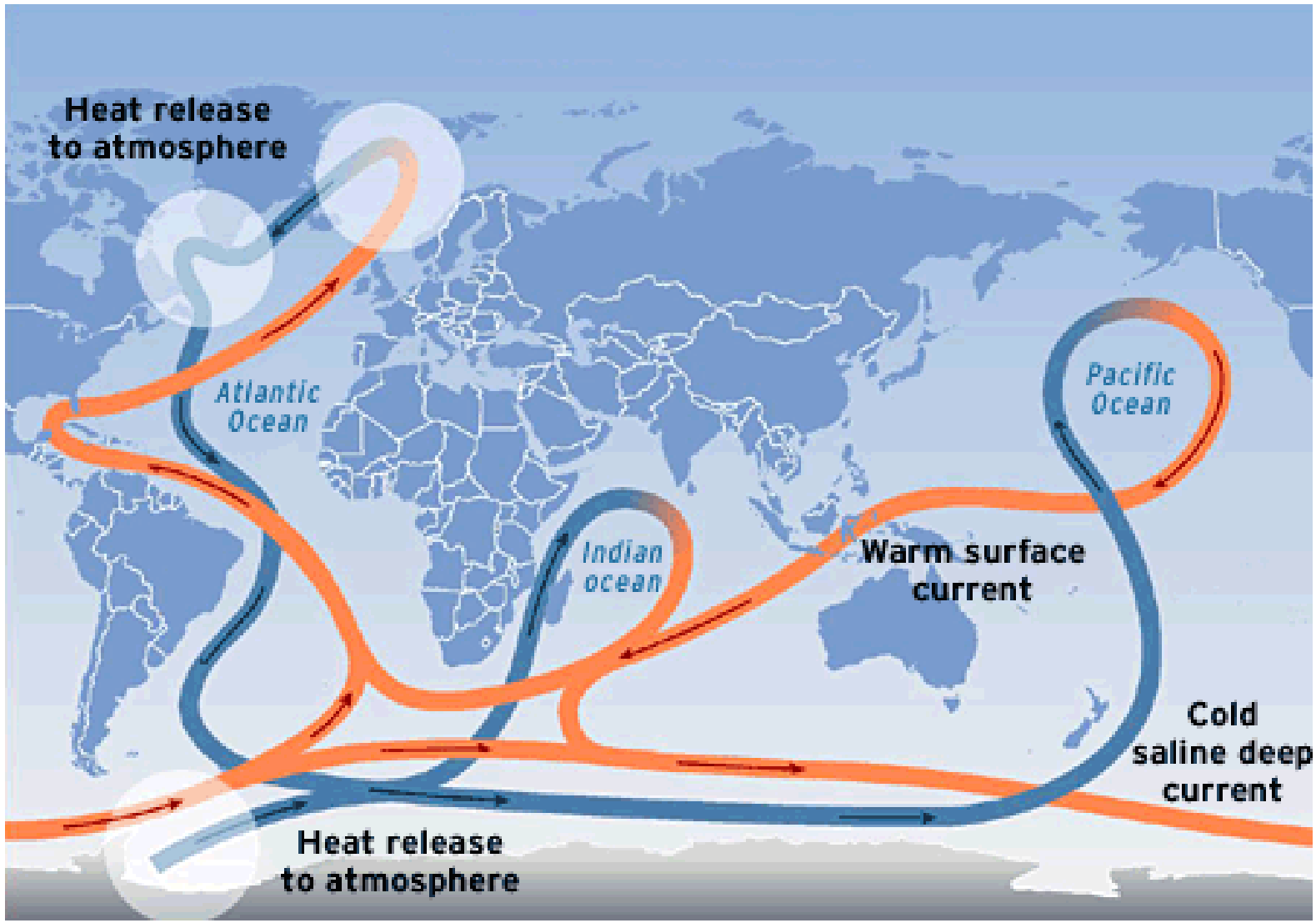


Stott et al, Science 2000

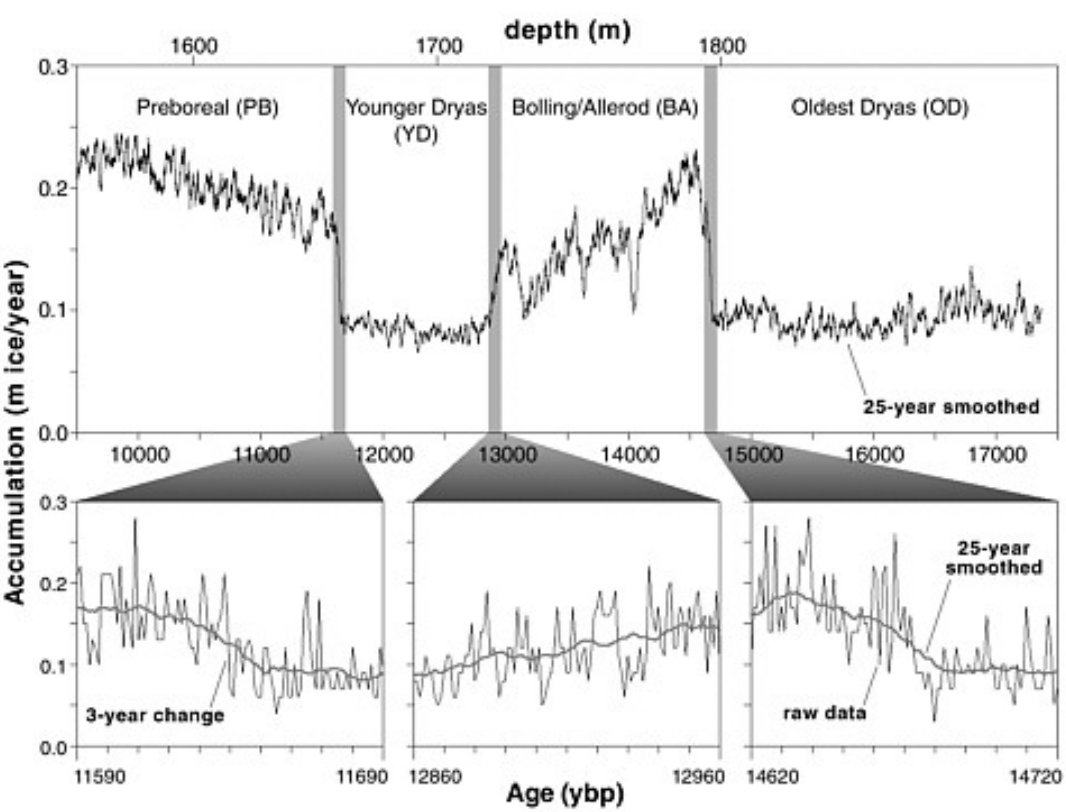
"Simulations of the response to natural forcings alone … do not explain the warming in the second half of the century"

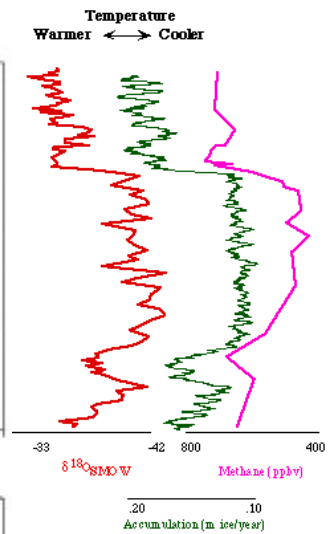
"..model estimates that take into account both greenhouse gases and sulphate aerosols are consistent with observations over this*period" - IPCC 2001

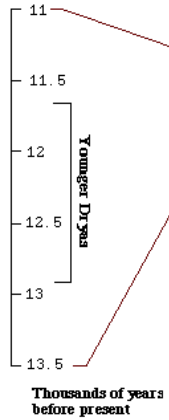
Thermohaline

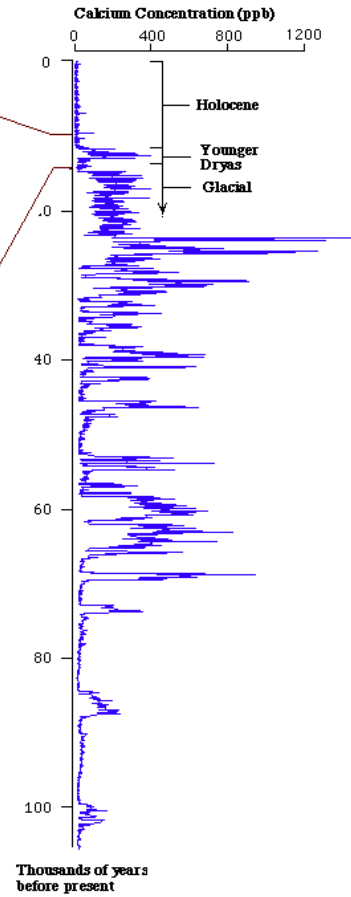


Paleoclimate









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Energy

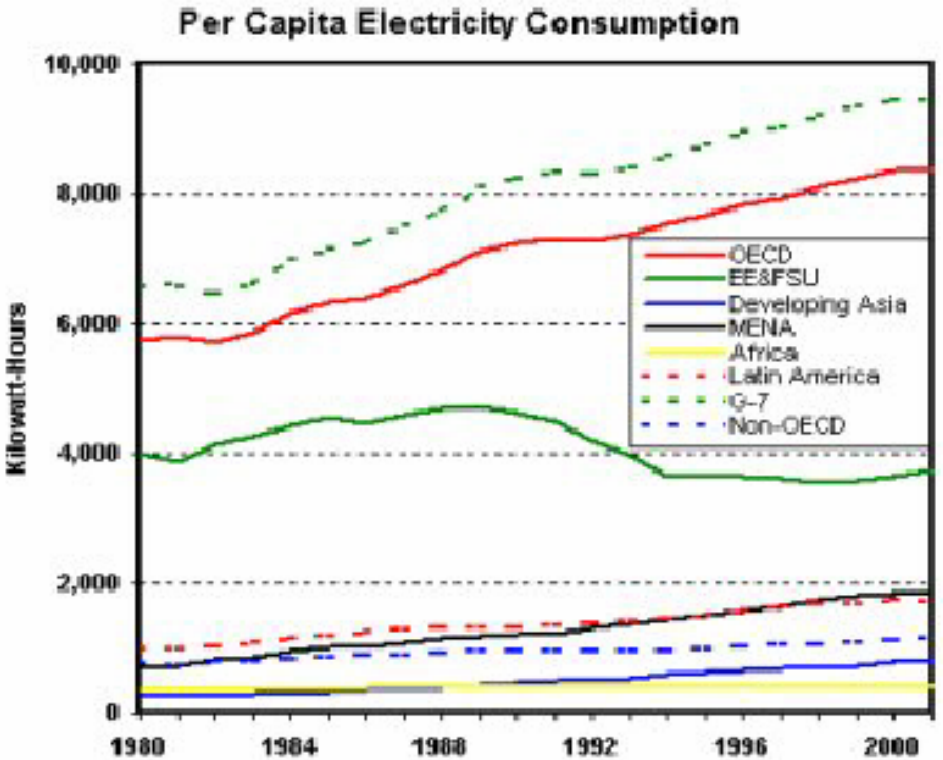
Can we reduce use of fossil fuel without stalling economic development?

Where are we headed?

World energy use?

- World energy use ≈ 1.2×10^{17} watt-hour
- Per capita energy ≈ 2×10^{7} watt-hour

- World Power ≈ 1.4×10^{13} watts
- Per-capita power ≈ 2000 watts



Total Electricity Use would be

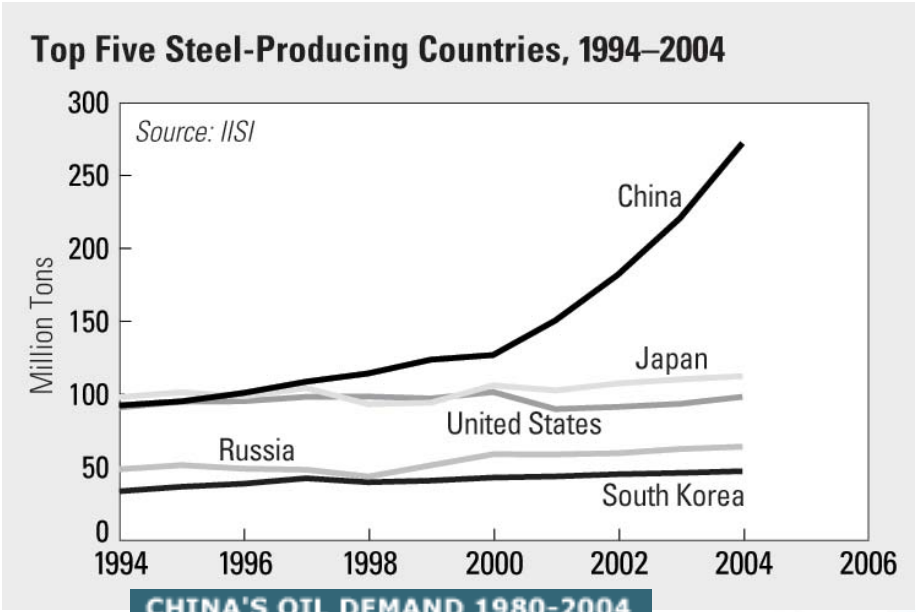
≈ 5 times @ <USA>

≈ 4 times @ <G7>

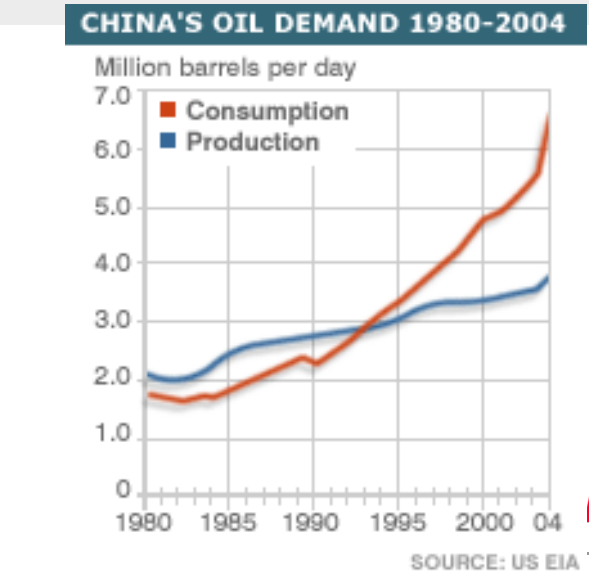
≈3.5 times @ <OECD>

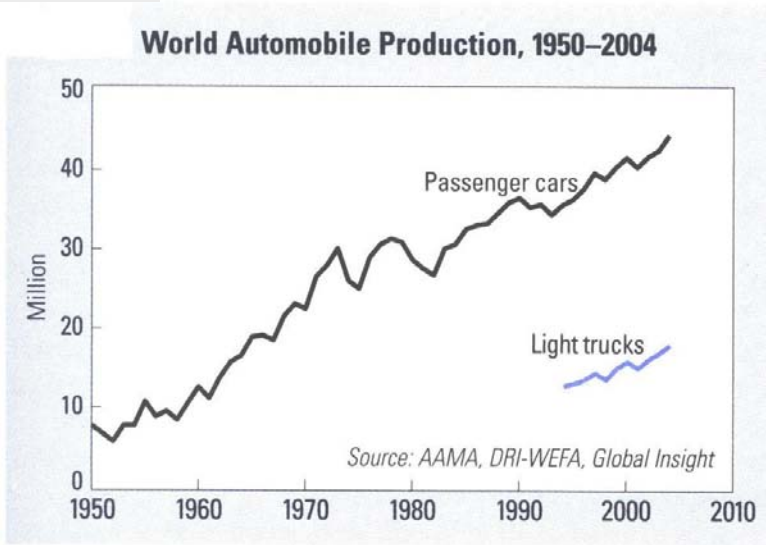
1 BTU = 1055 joules = 0.293 watt-hour

China and India are developing and they want more oil, gas, steel, cement, food, …



	2002	2003	2004
China GDP	$1.3T	$1.4T	$1.6T
China Oil	4.92Mbo	5.55	6.63
India GDP	$0.51T	$0.6T	$0.64T
India Oil	2.3Mbo	2.4	2.6





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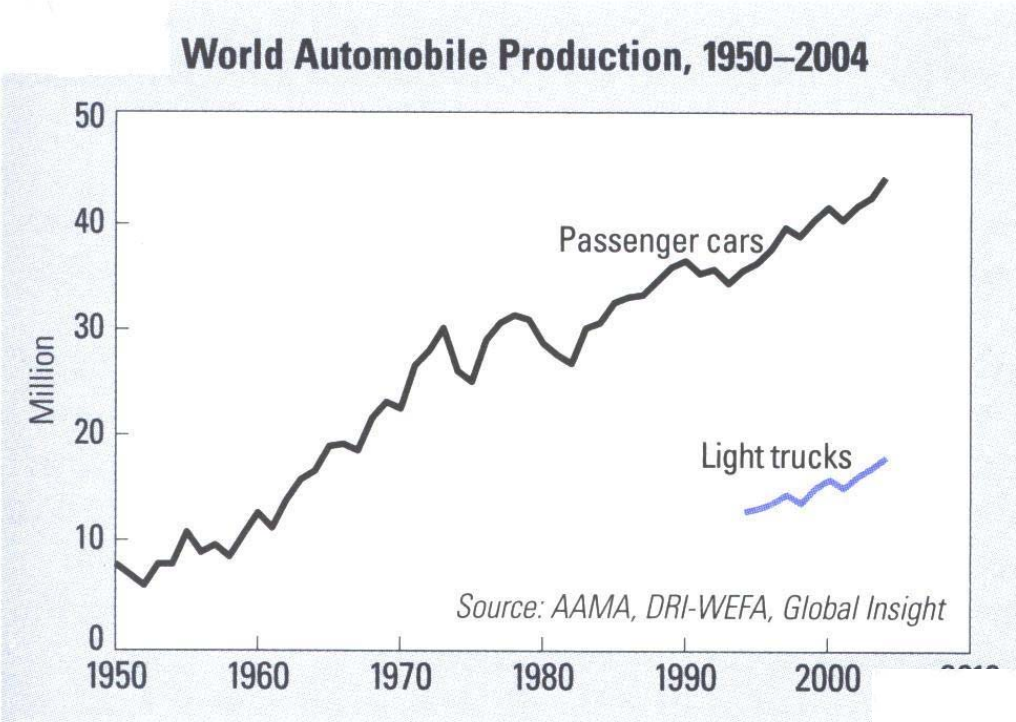
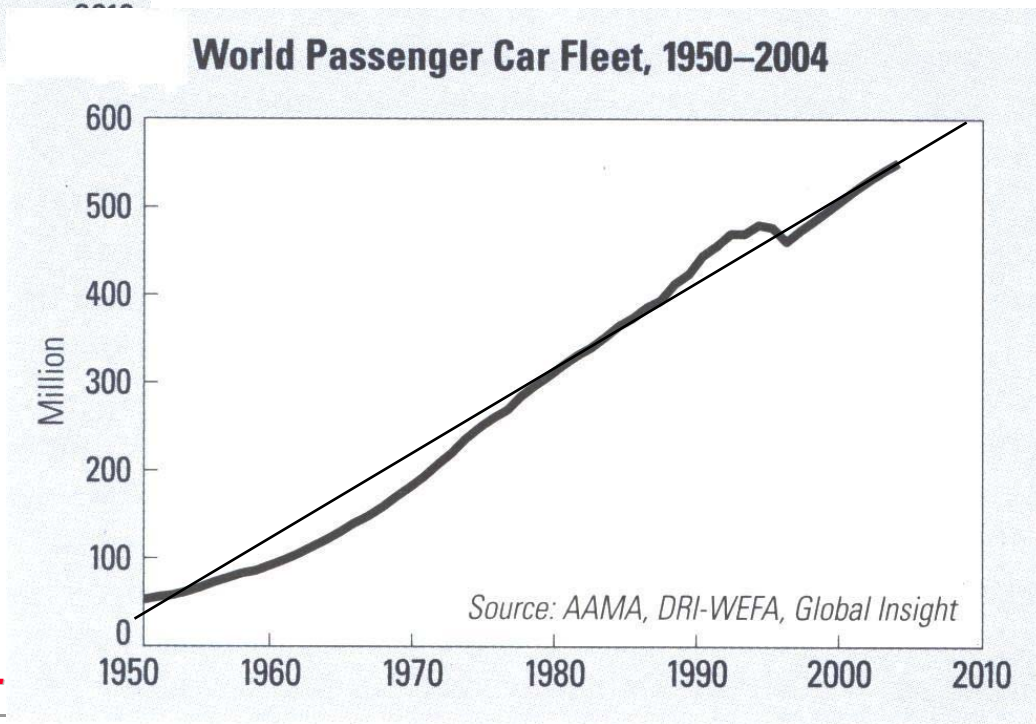
Energy



The world fleet of ~600 million cars/trucks need liquid fuel



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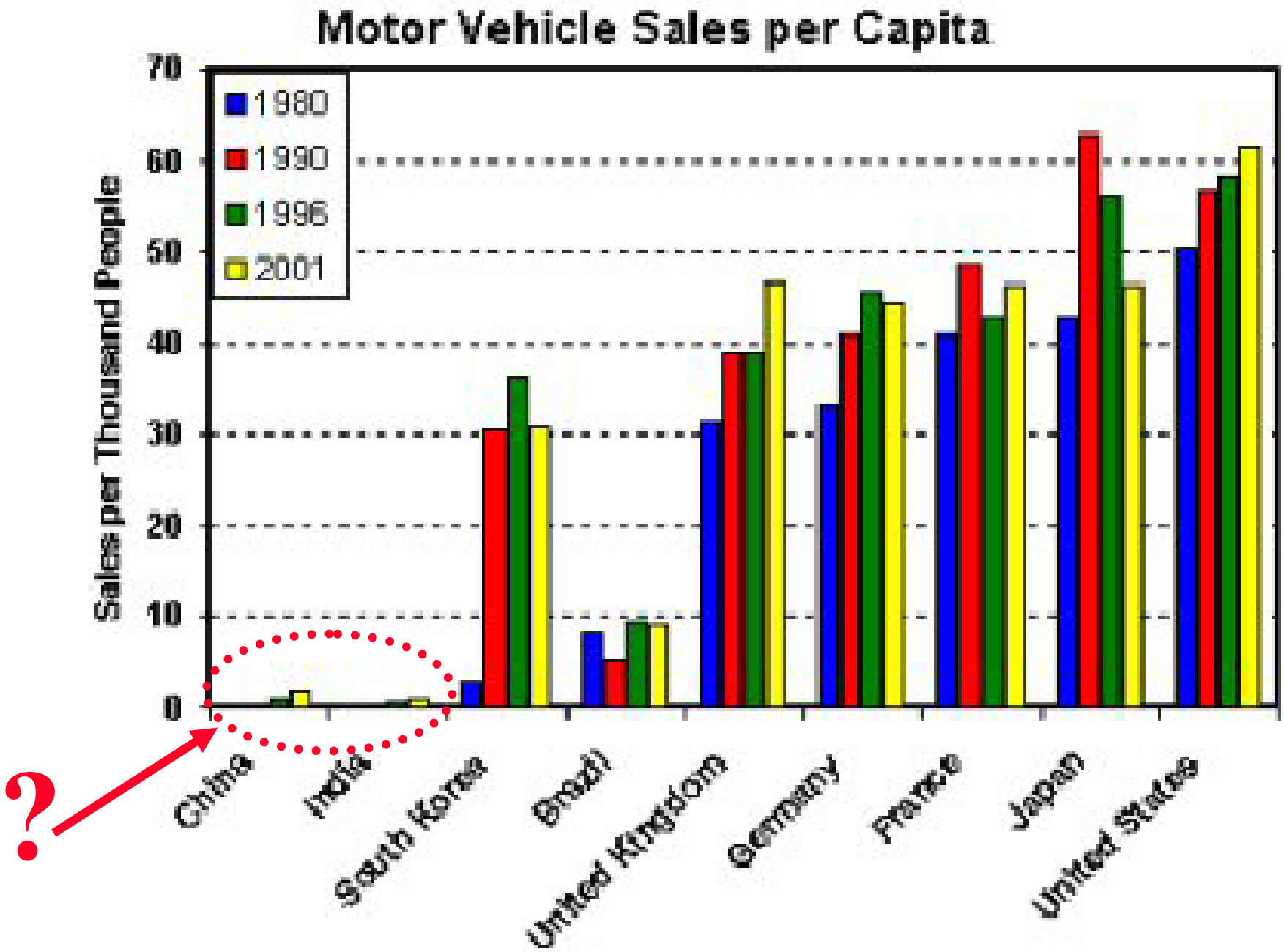
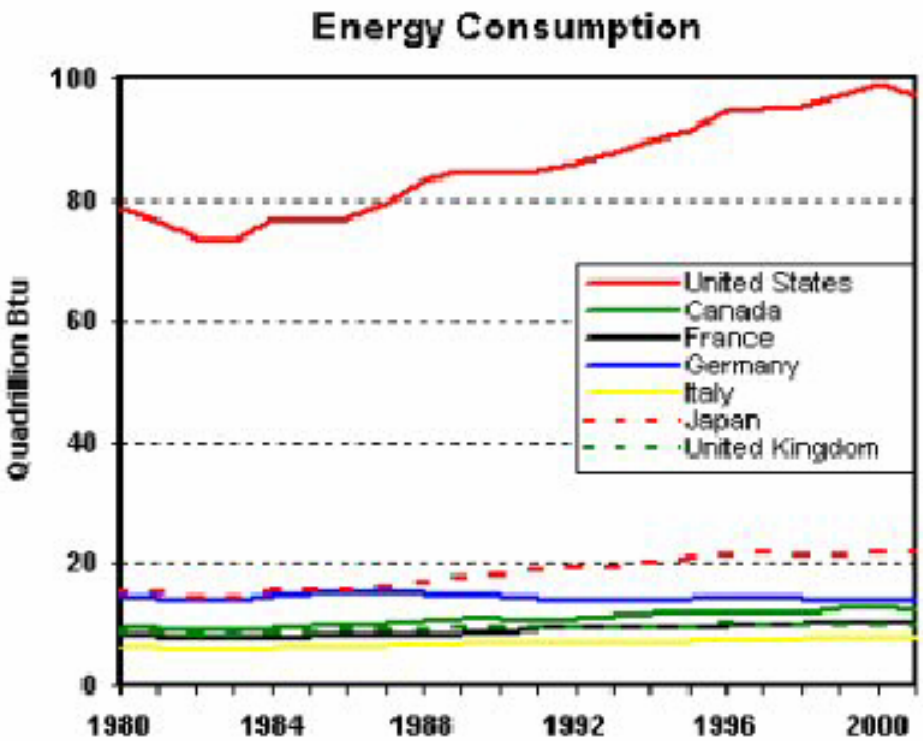

Motor Vehicle Sales per Capita
Sales per Thousand People
70
60
50
40
30
20
10
0
1980
1990
1996
2001
China
India
South Korea
Brazil
United Kingdom
Germany
France
Japan
United States
?

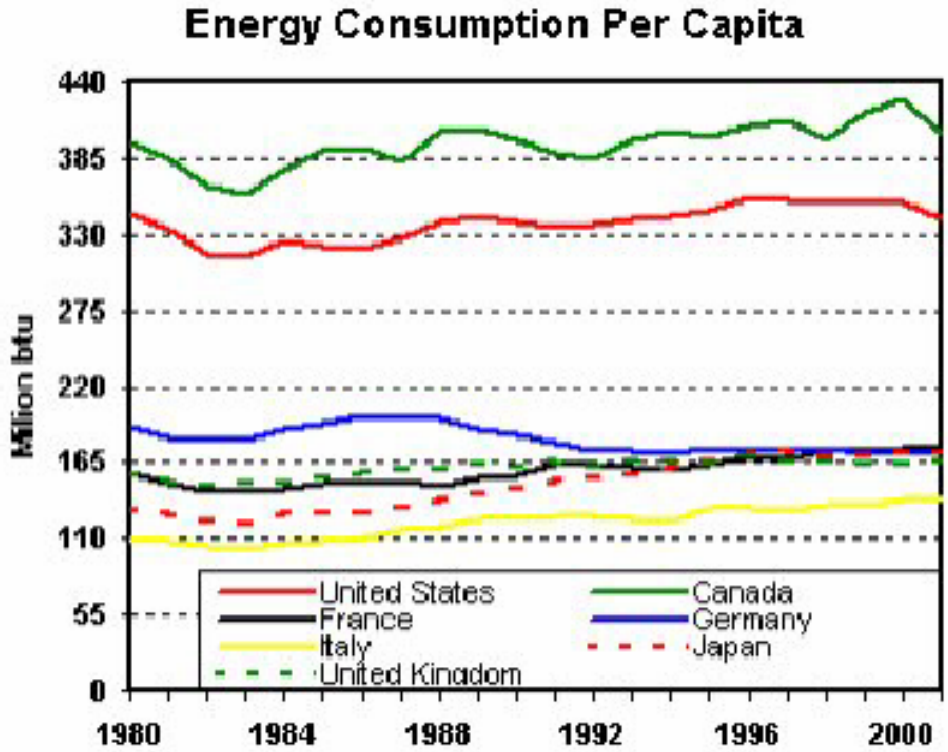
If we don't want China, Pakistan, India, Bangladesh, Central Asia, Africa, … to fail, they need to develop

- If we want them to develop they must have energy!
- How much energy?
- How can we help them get clean energy?

What is the global mean energy/per capita we should aim for?

G-7 Energy Consumption





Japan, Germany, UK, France show a plateau at ~165 M btu/per capita → 5.5 kilowatt. The current global mean is ~2 kilowatt. How do we get it to 5.5kw?

NEED

- Cheap
- Clean
- Copious

ENERGY

How do we help tailor the right mix for a given nation?

In short all three

- National and International security
- Economic development
- Environment

Point to the same thing

1. Need to increase non-fossil sources in the mix
2. Clean use of fossil fuels
3. More efficient use of energy
4. Conservation of fossil fuels

Start major implementations of 1-4 now

Long term musts

We must have an alternate energy carrier/storage to fossil fuels that is fully functional by 2030

Carbon sequestration by 2020

Short term Options: Transportation

- Change lifestyles
- Clean (coal → oil)
- Unconventional oil

Achilles Heel: Transportation

- Current alternatives can replace gas and oil for electricity generation
- The problem is in transportation. There does not exist a viable alternative to gasoline yet!

Figure 2. Delivered energy consumption by sector, 1970-2025 (quadrillion Btu)

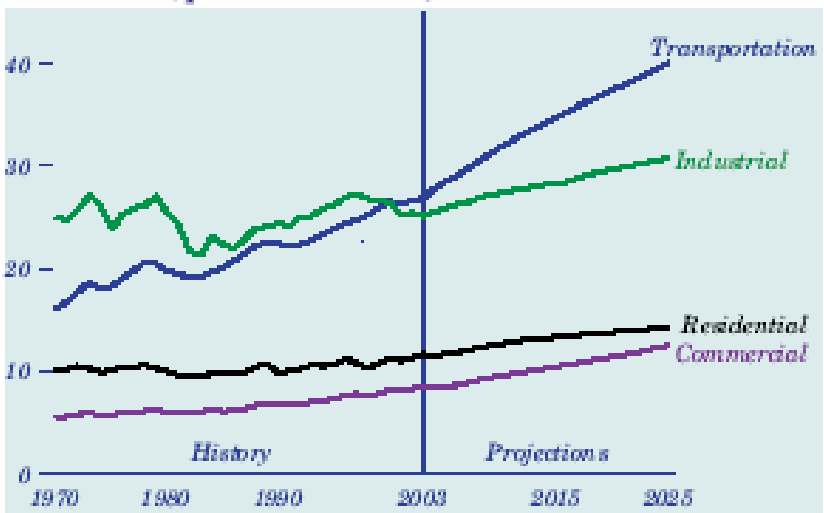
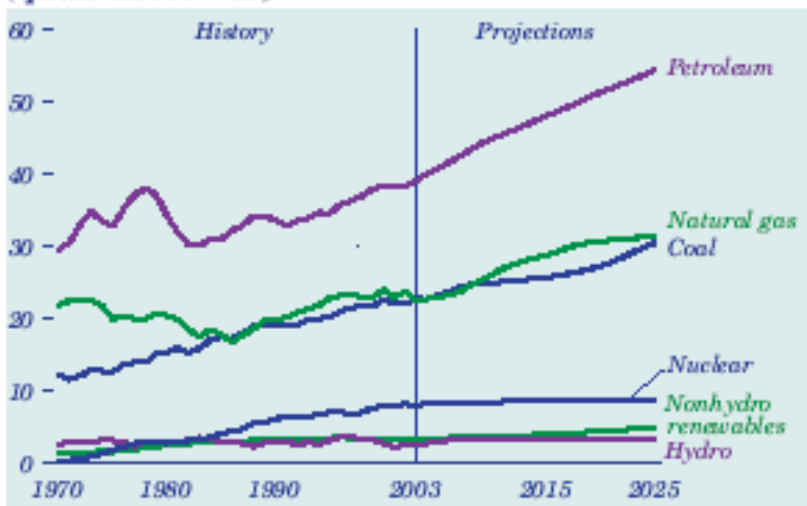


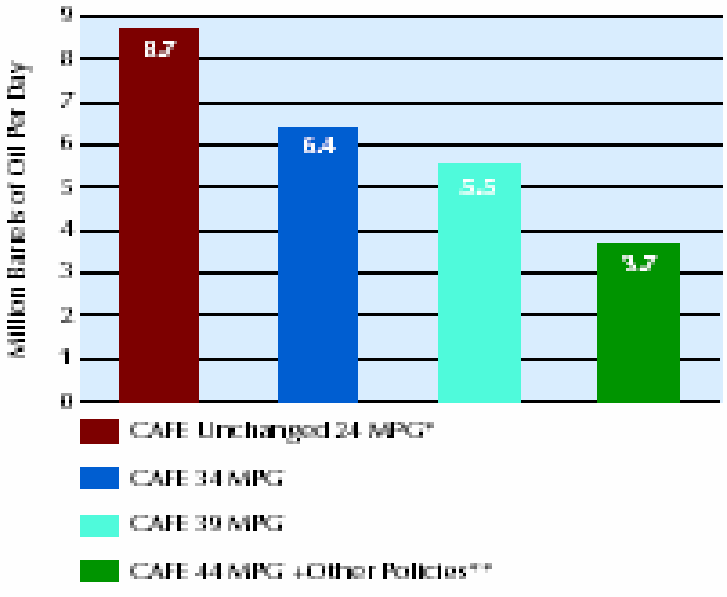
Figure 3. Energy consumption by fuel, 1970-2025 (quadrillion Btu)



Fuel efficiency: a case for hybrids

Projected Growth in Daily U.S. Oil Demand by 2025 Under Various Fuel Economy Scenarios

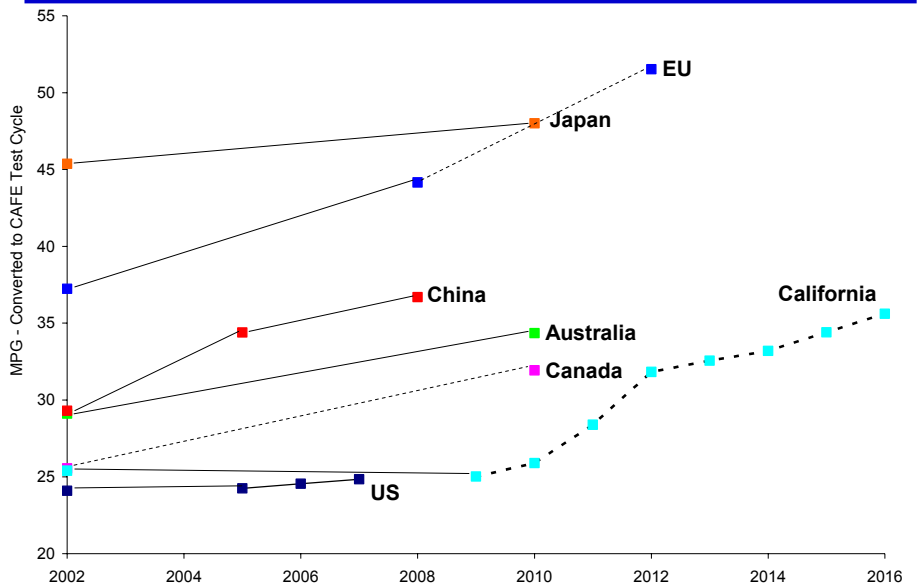
New passenger vehicle fuel economy standards will help reduce projected growth in U.S. petroleum demand.



* Combined car/light truck fuel economy level.
** Other policies include standards for heavy-duty tractor-trailer trucks, replacement tires and renewable fuel deployment policies.

Data Source: NCEP NEMS Modeling

We have lagged on CAFÉ



Has cheap gasoline and electricity lead to complacency?

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Coal → Oil

- 1 ton of coal → 5.5 barrels of oil = 0.75 ton of oil
- To replace 10% of world crude by synthetic from coal would need processing 1.54 million tons of coal a day (USA daily production is ~3 M tons)
- 72% more CO_2 is emitted when gasoline is produced from coal than from crude
- Costs $15/barrel to produce oil from coal versus $1-2 for Saudi oil. Syn oil becomes economical for > $30.
- Need to remove sulphur, mercury, arsenic, ….

Needs CO2 sequestration

Unconventional sources

- Extra-heavy oil (Orinoco oil belt in Venezuela)
- Tar sands (Athabaska Canada, in-situ mining)
- Shale oil (most resources in North America)
- Synthetic crude (from tar, gas, coal)
- Coal bed methane
- Methane hydrates

Need more R&D to scale up

Unconventional sources

- Need more energy and water to extract
- Are more polluting
- Have larger environmental impact

Consequences of production at 10s of megatons a day are unknown

Example: Tar Sands

- 2 tons bitumen + energy + 3 barrels of water $\rightarrow$ 1 barrel oil
- Much more sulphur, mercury, ... have to be captured and processed.
- Tailings slurry contains heavy metals, inorganic salts and hydrocarbons
- Production cost: Syncrude Canada = \$12 per barrel of oil versus \$1-2 for Saudi oil.
- Commercially viable for > \$25/barrel

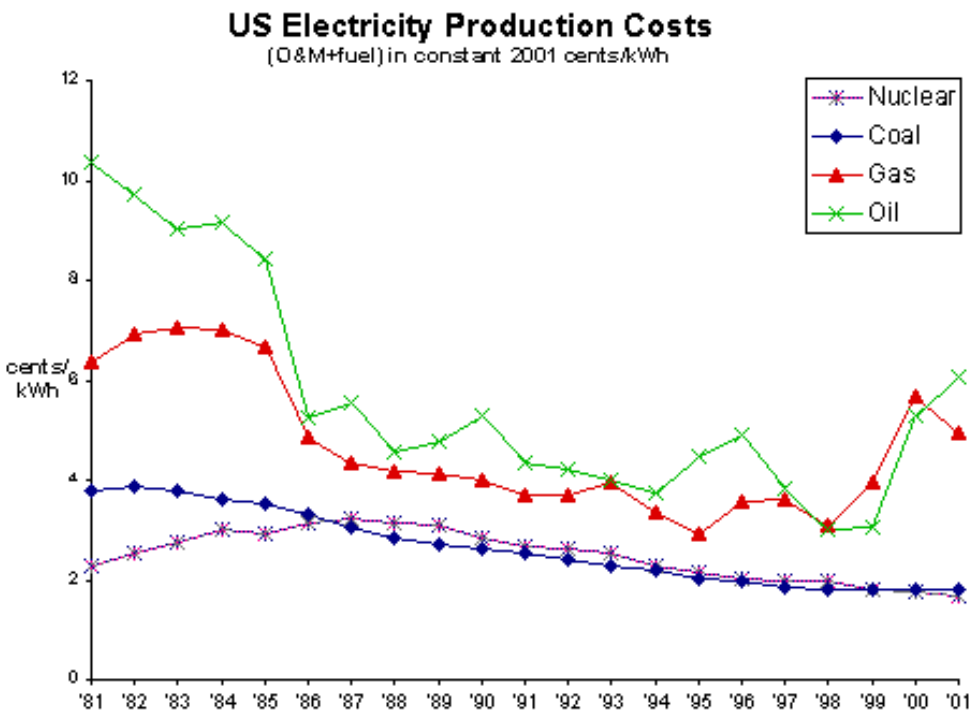
Power generation

Short term Options

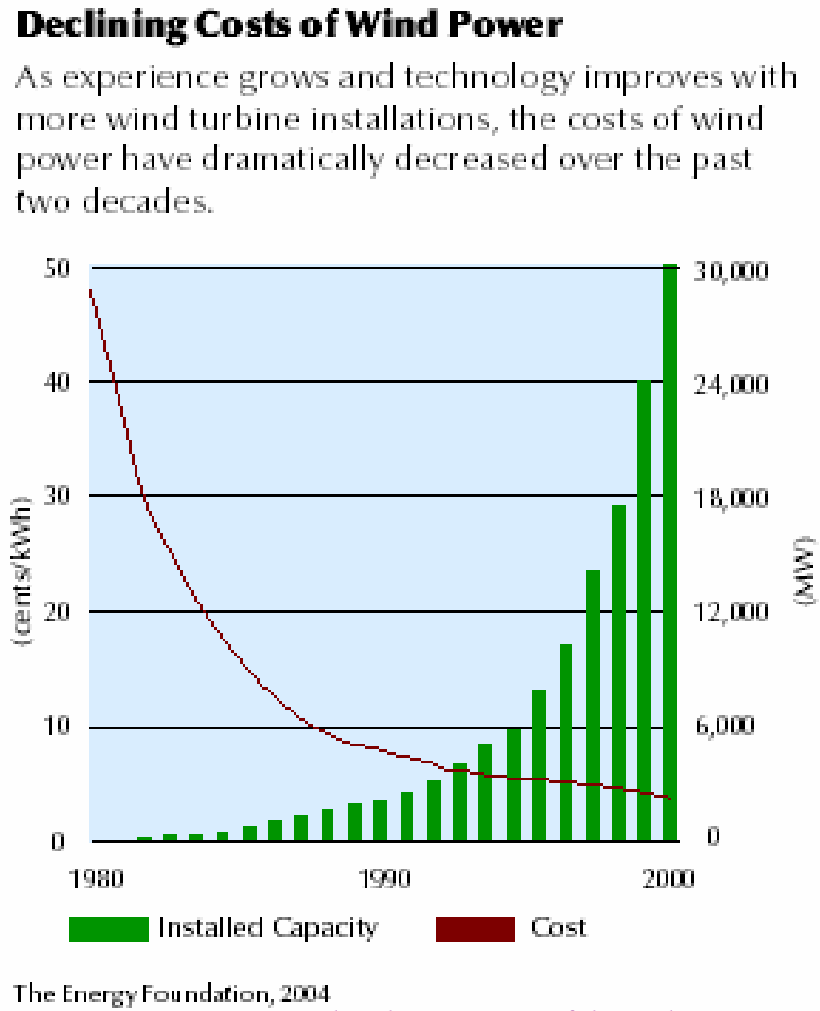
- Clean coal
- Nuclear
- Wind
- Solar and Biomass
- Hydro

What does the market say?

Cost of power generation



These costs do not include capital costs or cost of waste management



Does not include cost of backup

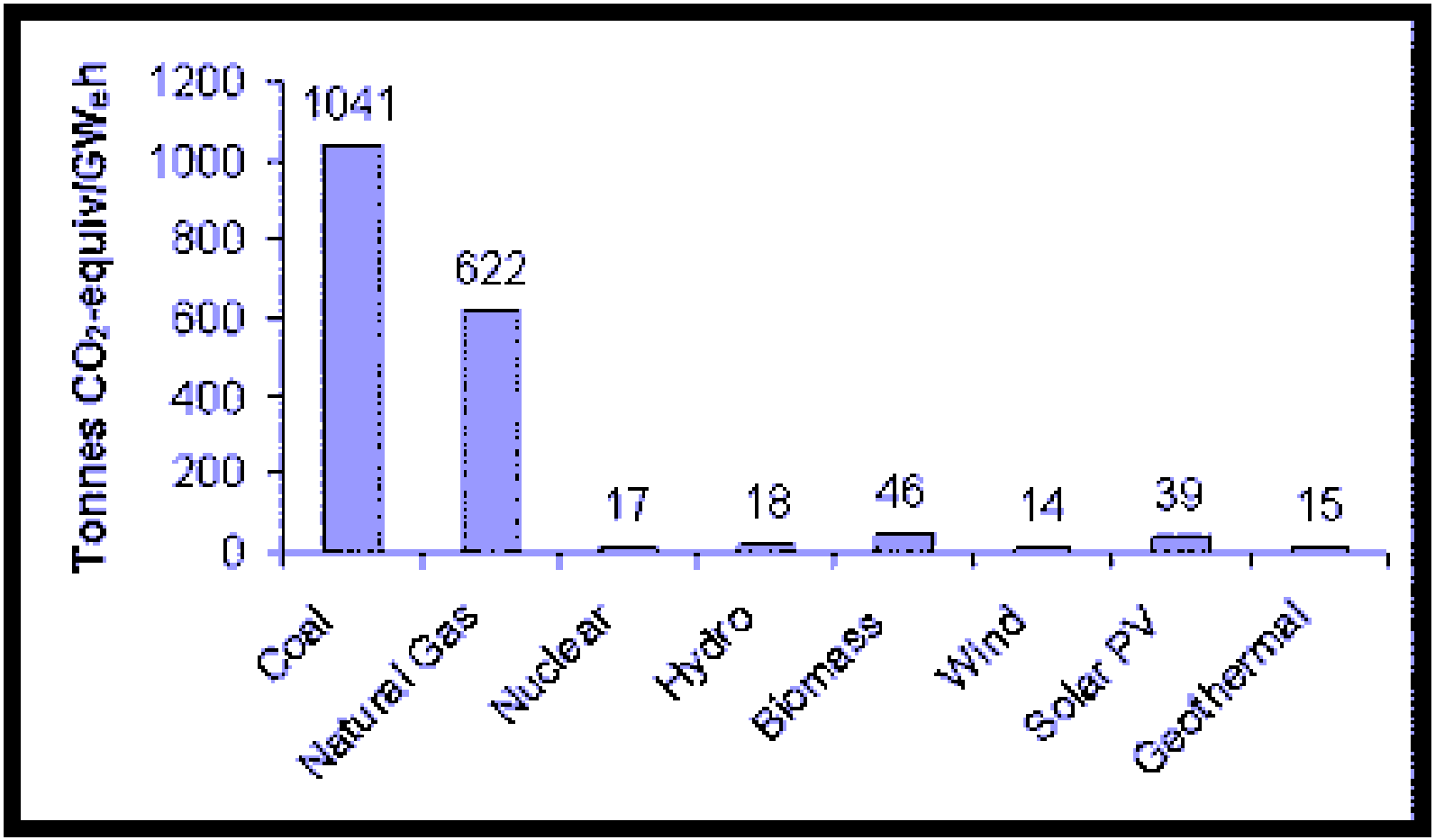
2004 cost of generating UK electricity (p/kWh) from a new plant

	Basic cost pence/kWh	With back-up	With £30/t CO_2 £110/t C
Nuclear	2.3	n/a	n/a
Gas-fired CCGT	2.2	n/a	3.4
Coal pulverised fuel	2.5	n/a	5.0
Coal fluidised bed	2.6	n/a	5.1
Onshore wind	3.7	5.4	n/a
Offshore wind	5.5	7.2	n/a

Installation cost and time for a new plant

	Installation Cost	Installation Time
Nuclear	$2 / watt	7-10 years
Coal	$1 / watt	3-5 years
Gas	$0.6 / watt	2-3 years
Wind	$0.7-1.0 / watt	months
PV	$8 / watt	weeks

The hidden and ignored environmental cost of CO2 emissions from fossil fuels



Comparison of life-cycle CO2 emissions from different electricity generation options. Emissions from oil are roughly in between coal and natural gas. (Source: "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis," Paul J. Meier, University of Wisconsin-Madison, August, 2002.)

Clean Coal Initiatives

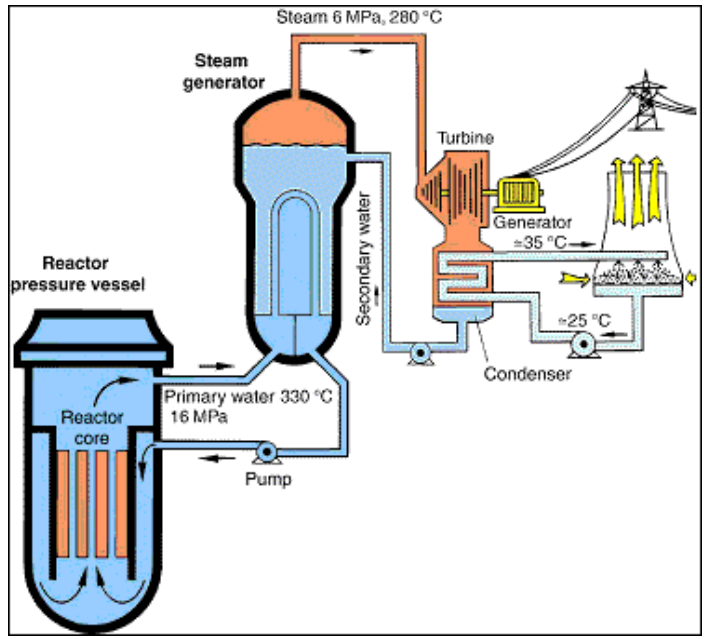
- Integrated Gasification Combined Cycle (IGCC)
- FutureGen
- Vision 21

When?

- **Multiple feedstock**
- **Higher efficiency (CC)**
- **Multiple products (modular)**
- **Zero polluting emissions**

Nuclear power "CO2 clean"

- Principles of nuclear fission are known
- Natural ^{235}U is a limited resource
- Issue of HEU and ^{239}Pu
- Generation IV reactors
- Breeder reactors?
  - $^{232}Th \rightarrow {}^{233}U$
  - $^{238}U \rightarrow {}^{239}Pu$



Nuclear Power (2004)

- 442 plants in 32 countries produce ~ 0.2 Terawatts. This represents 6.7% (18%) of world energy (electricity) use.
- No new plants in the US since 1978
- Typical lifetime of operation ~ 40 years
- 442 plants produce ~2000 tons of highly radioactive waste fuel per year
- Issues of proliferation of HEU and Pu^{239} and diversion to nuclear weapons

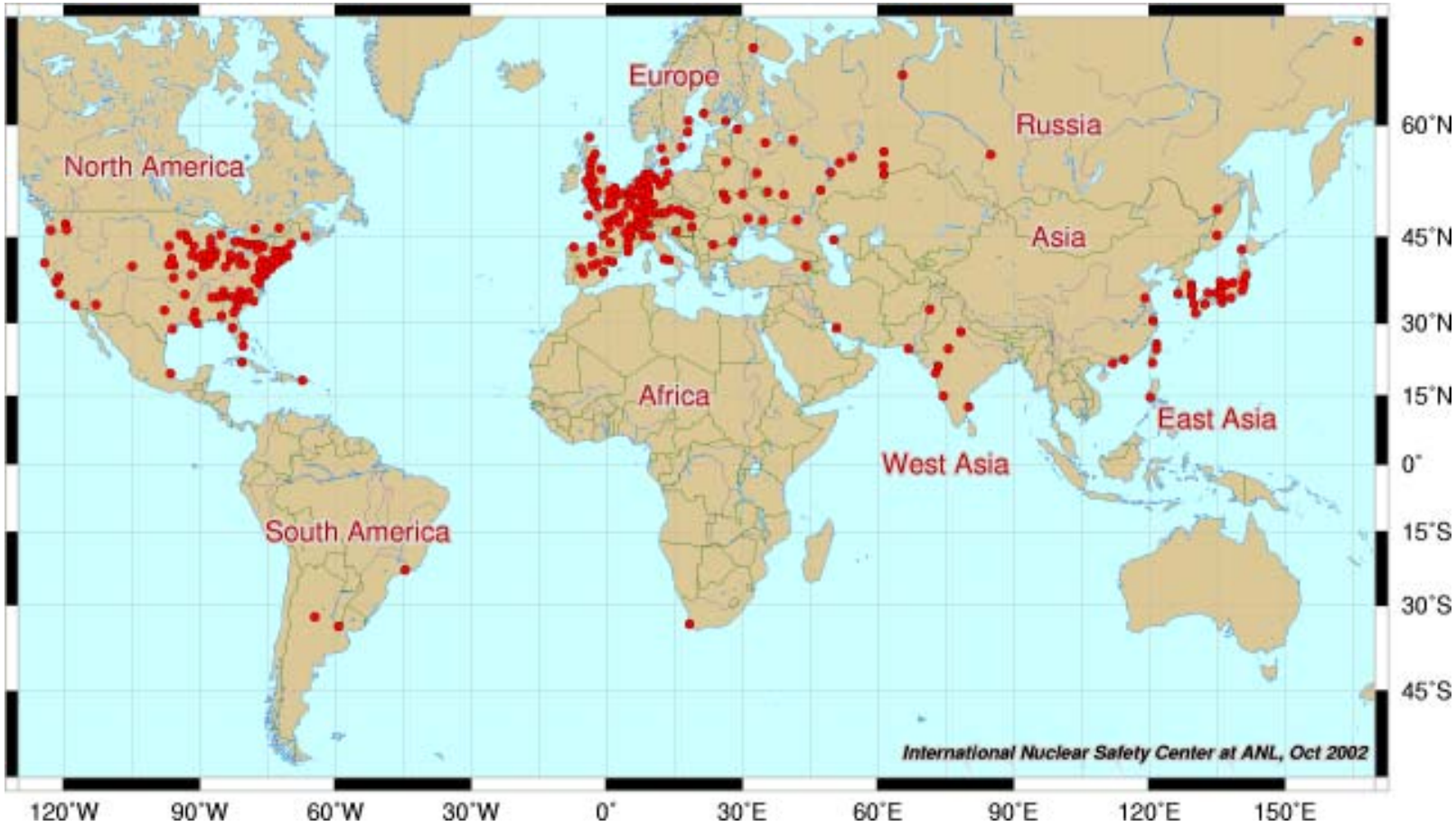
USA is barely at the table

- 32 countries have nuclear energy as part of their energy portfolio.
- Many more want, and will try to get it!
- These countries are designing their own strategies and solutions.
- The US is not leading the discussing on the future of energy, in particular nuclear energy, non-proliferation and waste management with them.

COUNTRY	**Nuclear Reactors** in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2003		Total Operating Experience to June 20004	
	No of Units	Total MW(e)	No of Units	Total MW(e)	TWh	% of Total	Years	Months
CANADA	17	12113			70.29	12.53	495	5
CHINA	9	6587	2	2000	41.59	2.18	43	5
FRANCE	59	63363			420.70	77.68	1375	8
GERMANY	18	20643			157.44	28.10	657	0
INDIA	14	2550	8	3622	16.37	3.30	230	5
IRAN			2	2111			0	0
JAPAN	54	45464	2	2371	230.80	25.01	1150	4
KOREA, REPUBLIC OF	19	15850	1	960	123.28	40.01	230	2
PAKISTAN	2	425			1.81	2.37	36	10
RUSSIAN FEDERATION	30	20793	3	2825	138.39	16.54	776	4
SPAIN	9	7584			59.36	23.64	223	8
SWEDEN	11	9451			65.50	49.62	316	7
UKRAINE	13	11207	4	3800	76.70	45.93	286	4
UNITED KINGDOM	27	12052			85.31	23.70	1343	2
USA	104	98298			763.74	19.86	2923	8
Total (15 countries)	**386**	**326,380**	**22**	**17689**	**2251**		**10083**	
Total (32 countries)	**442**	**363,380**	**27**	**22676**	**2525**		**11364**	

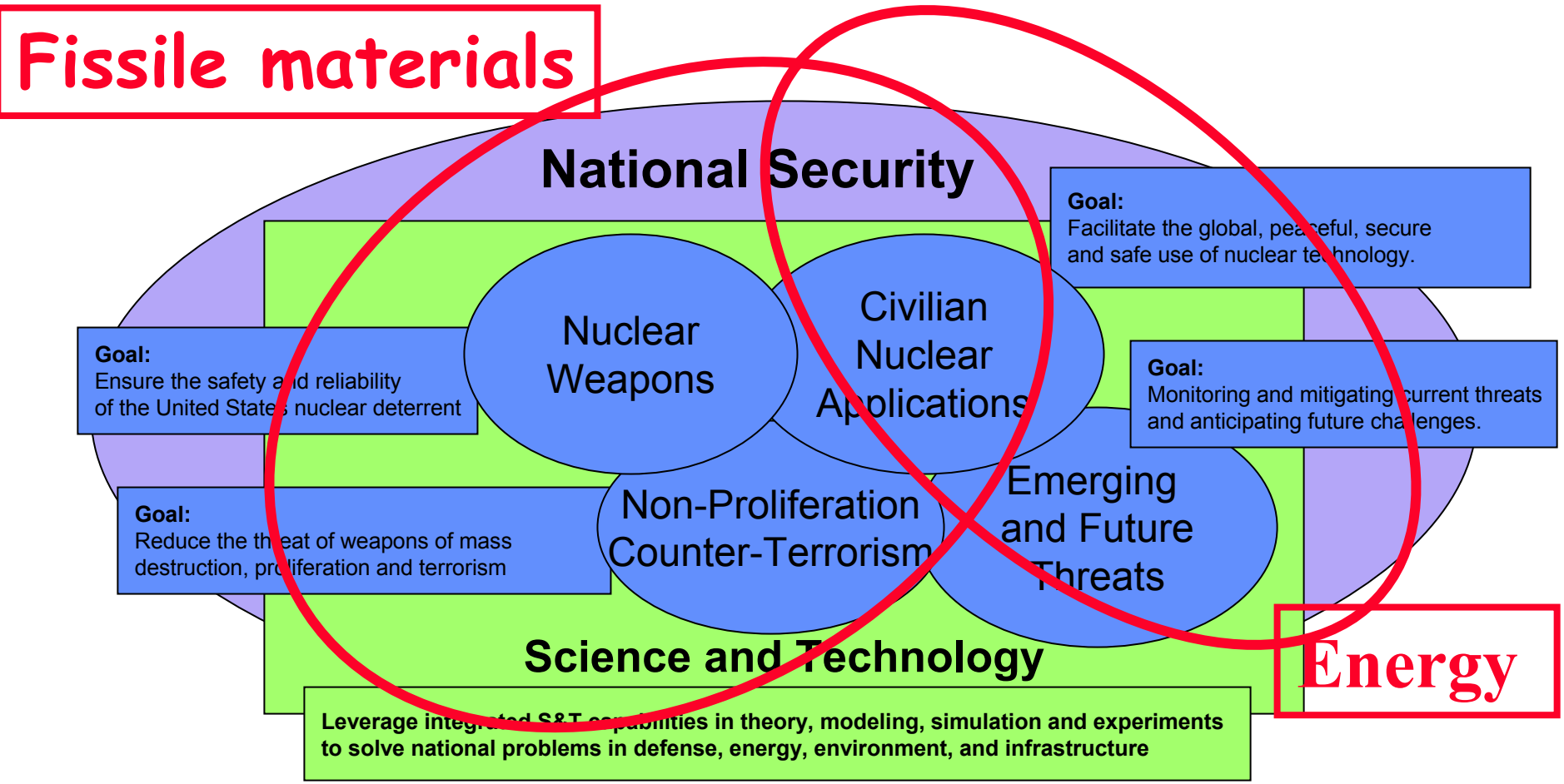
WORLD POWER REACTORS

[Source: INSC - Argonne]

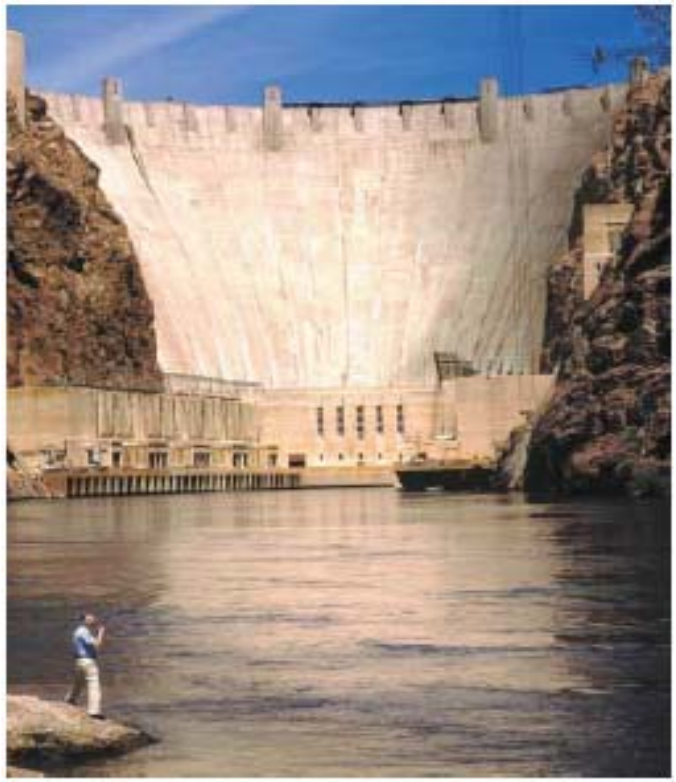


To replace 10Terawatts by nuclear power would require 10,000 one GW plants – 1 new plant a day for 30 years

Drivers and Concerns



Renewables

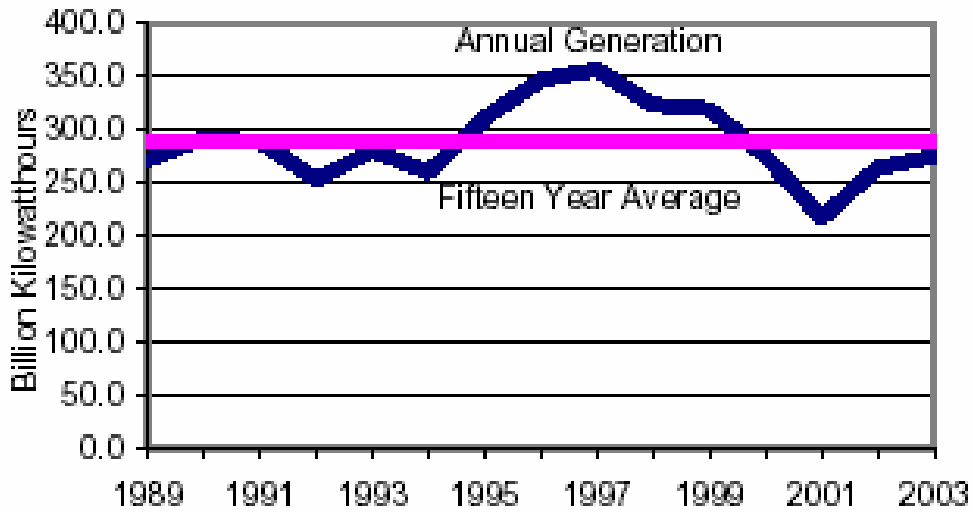


Hydroelectric Dams

- **Electricity generation**
- **Water management**

- **Silting**
- **Ecological impact**
- **Large versus small dams**

NO significant growth



Sources: 1989-1998: Energy Information Administration, Annual Energy Review 2002, DOE/EIA-0384(2002) (Washington, DC, October 2003), Table 8.2a. 1999-2003 Table 4 of this report.

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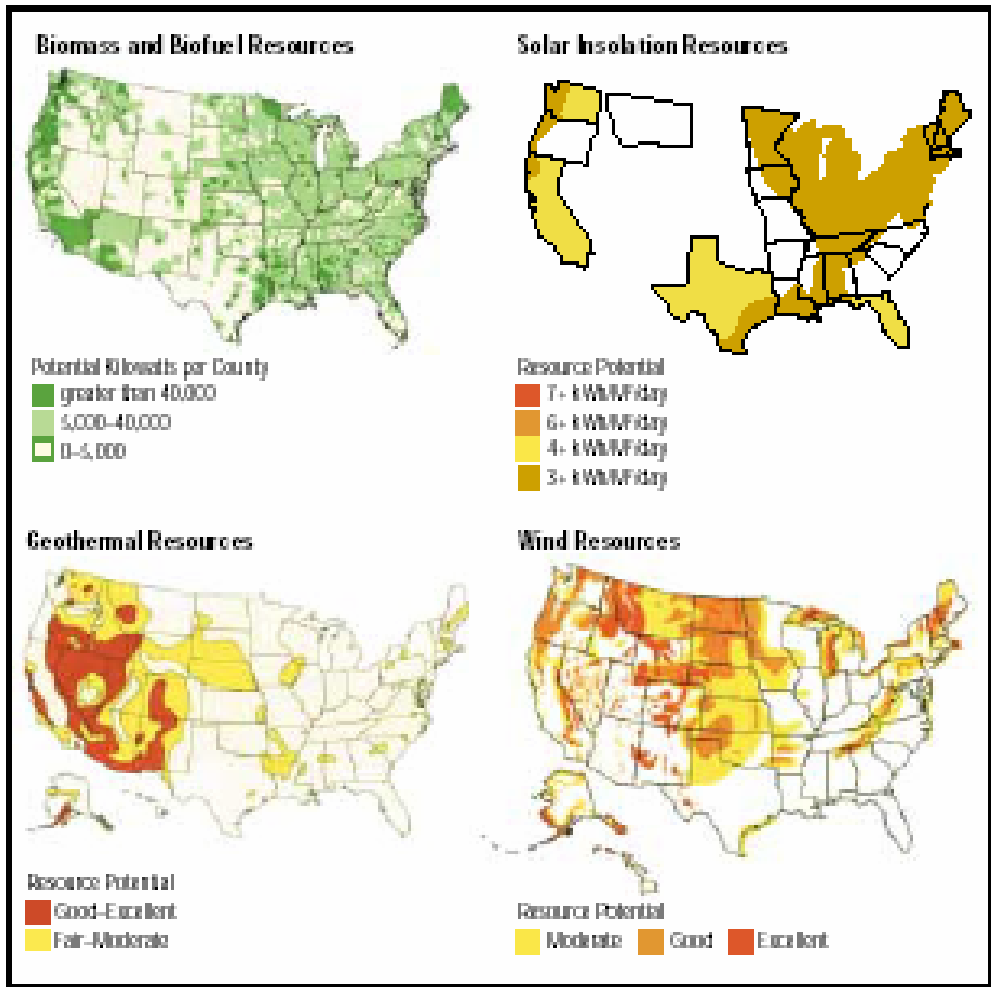
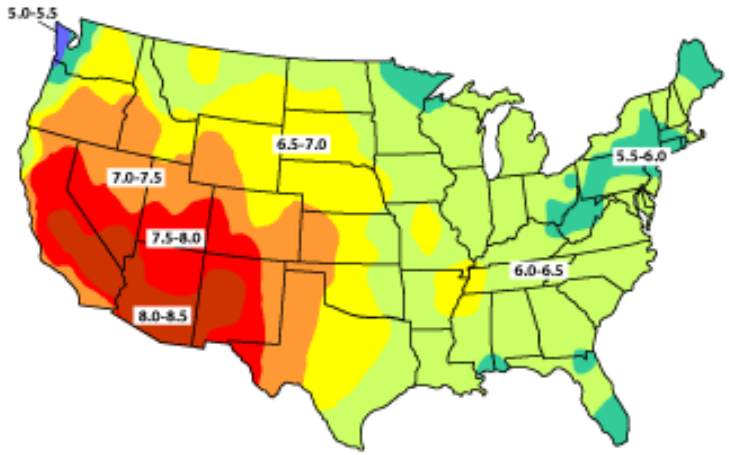
http://t

Wind and Solar

U.S. Resource Potential for Renewable Energy



Almost every state has the potential for wind energy and for biomass and biofuel production. The Southwest has the greatest potential for solar energy, and geothermal energy resources are most abundant in the West.

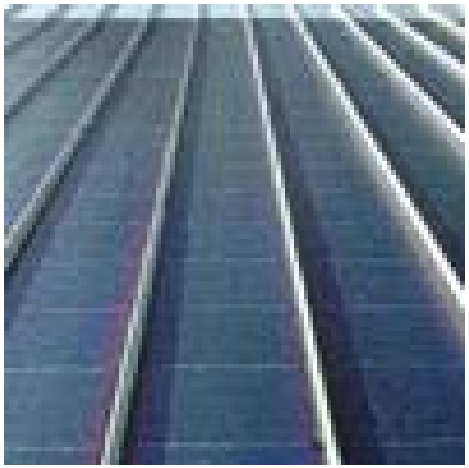


kWh/day in June

Power input is intermittent → need ~3 times the demand OR storage to function without backup

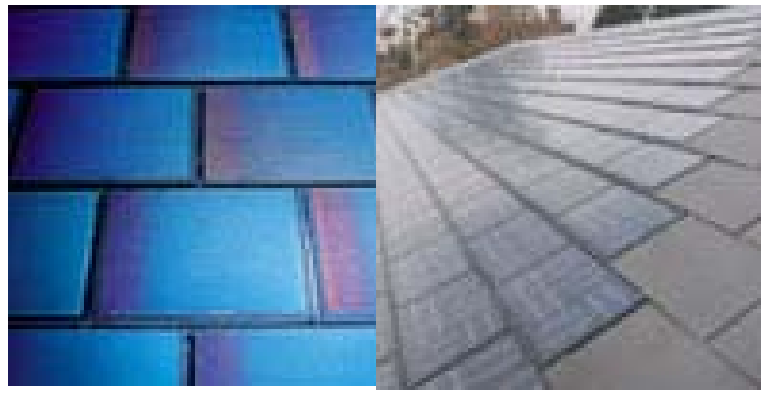
Solar PV options reaching 15% efficiency

30-45 watts / sq. meter

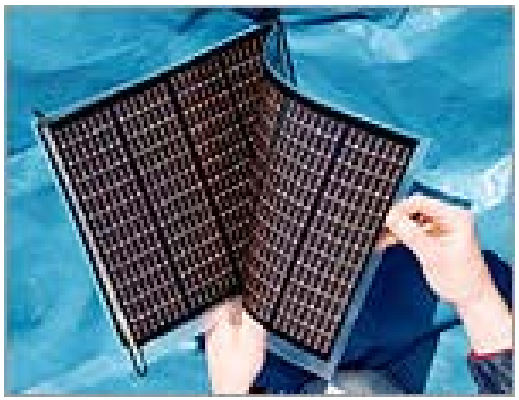


Laminate

Troughs

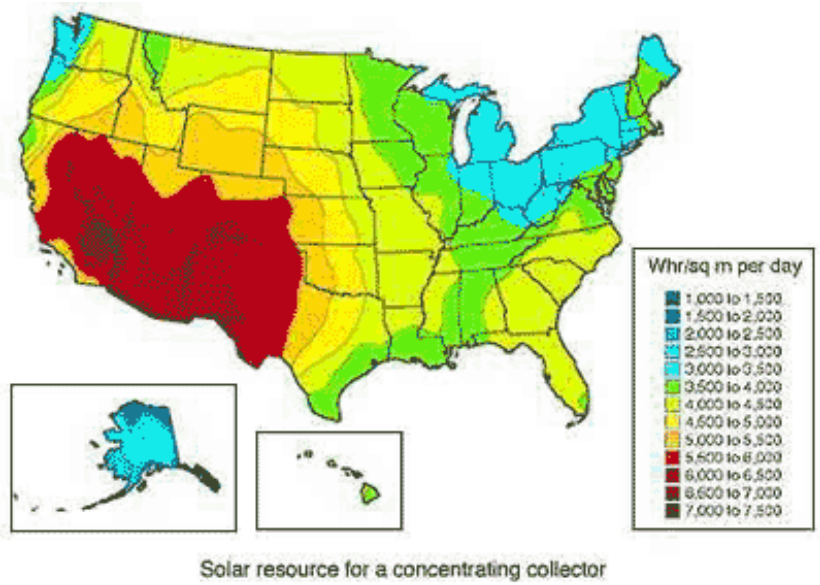


Tiles /Shingles



Thin films

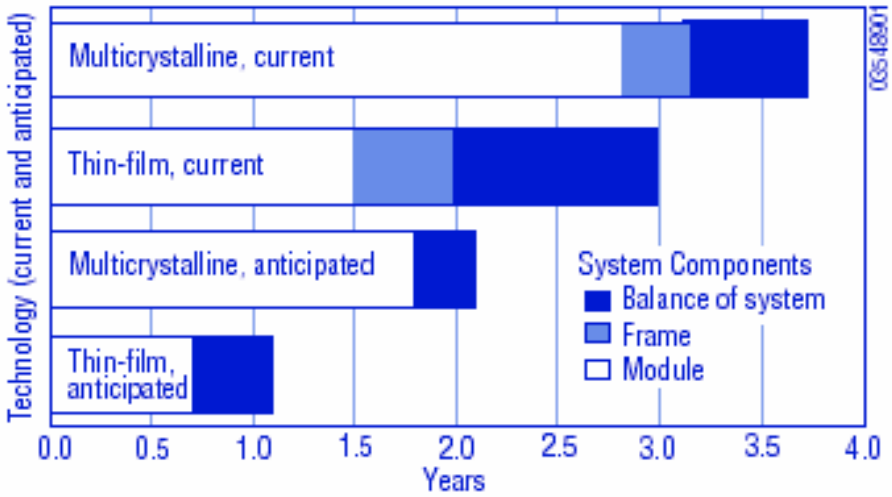
PV polycrystalline



Solar resource for a concentrating collector

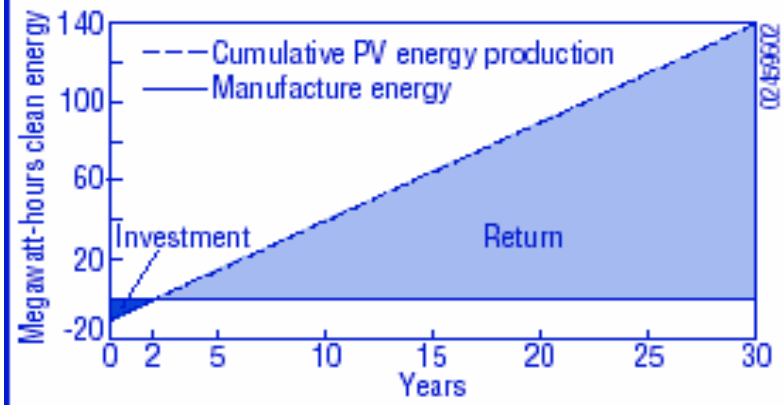
Payback of PV: homes & buildings

Figure 1. Energy Payback for Rooftop PV Systems



Reaping the environmental benefits of solar energy requires spending energy to make the PV system. But as this graphic shows, the investment is small. Assuming 30-year system life, PV systems will provide a net gain of 26 to 29 years of pollution-free and greenhouse-gas-free electrical generation.

Figure 2. Cumulative Net Clean Energy Payoff

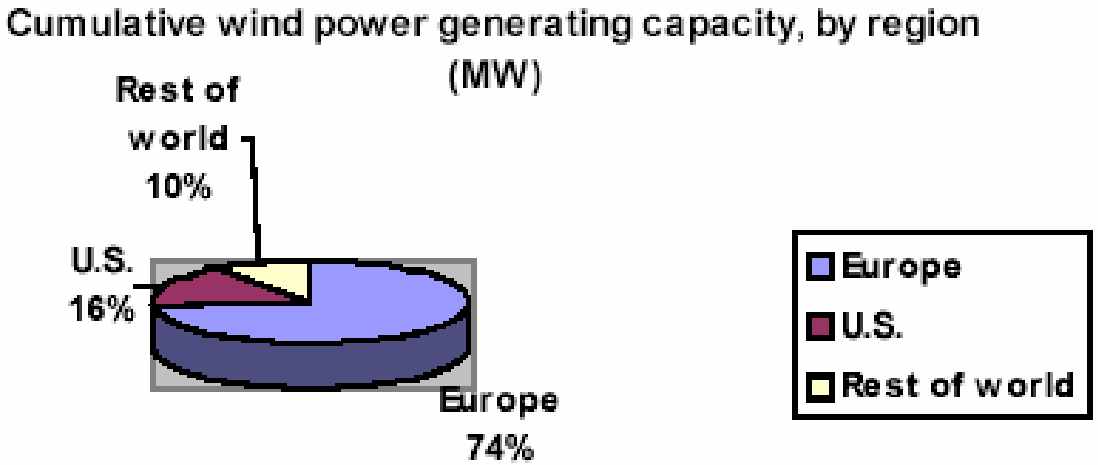


PV systems can repay their energy investment in about 2 years. During its 28 remaining years of assumed operation, a PV system that meets half of an average household's electrical use would eliminate half a ton of sulfur dioxide and one-third of a ton of nitrogen-oxides pollution. The carbon-dioxide emissions avoided would offset the operation of two cars for those 28 years.

For a 2 kilowatt system installed for $16000

My gas utility bill was $1800 for last 12 months

Wind 2003: Total=40 gigawatts peak

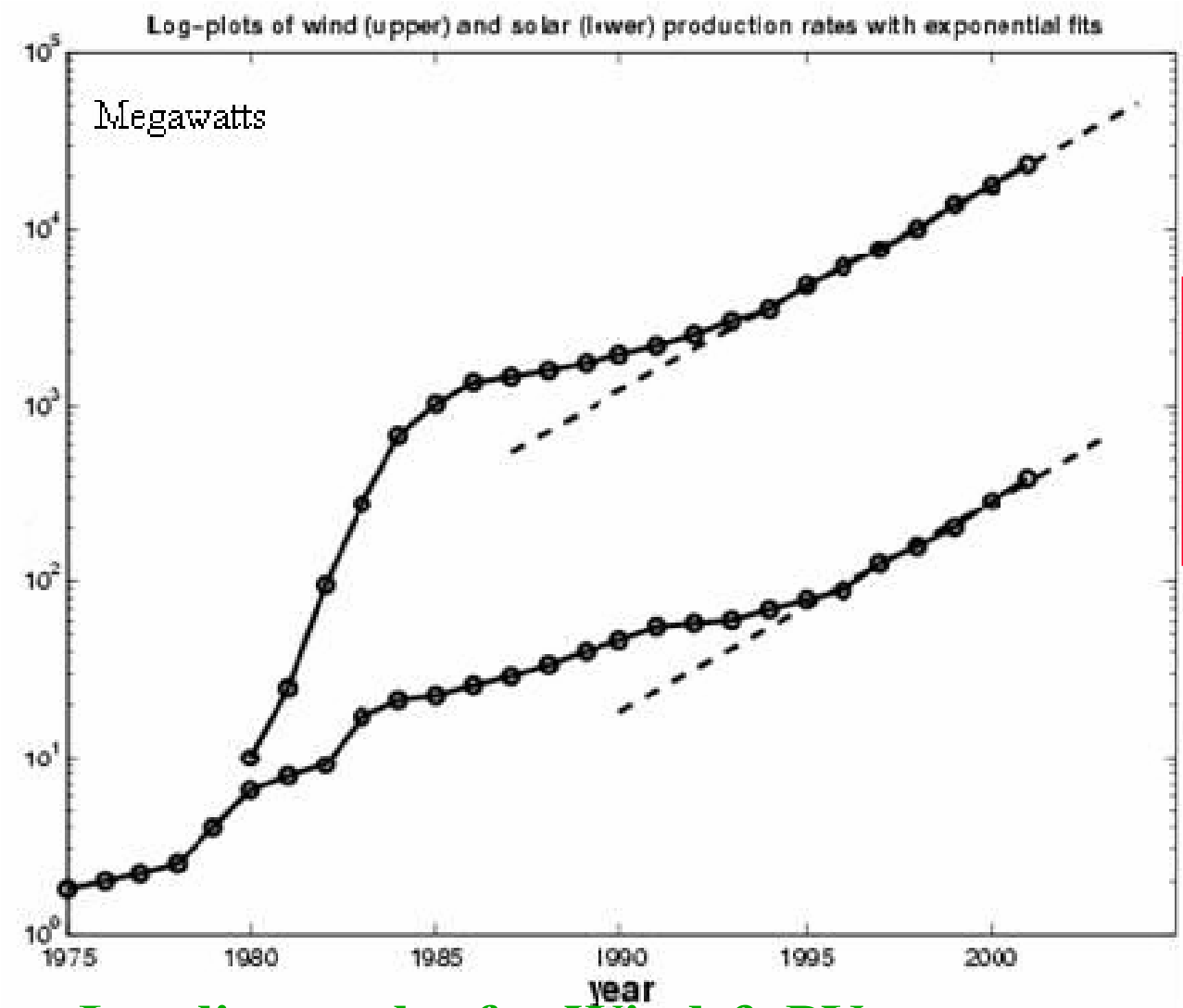


Worldwide, Europe and the U.S. account for 90% of cumulative capacity.

Top five wind energy markets (installed capacity, in MW)	2002 Additions	2002 Year End Total	2003 Additions	**2003 Year End Total**
Germany	3,247	12,001	2,645	**14,609**
United States	410	4,685	1,687	**6,374**
Spain	1,493	4,830	1,377	**6,202**
Denmark	407	2,880	243	**3,110**
India	195	1,702	408	**2,110**

Source: AWEA

International wind & PV growth



1995-2002 show ~30% growth

Source: Ben Luce

Log-linear plot for Wind & PV

Wind & PV: Long Way To Go (2003)

World energy use ~ 420 quads ~ 1.2×10^{17} W hr

- Power from Wind ~ 3.5×10^{14} W hr (4×10^{10} W)
- New capacity(2003) ~ 7×10^{13} W hr (8.2×10^{9} W)
- Cost: 3-6 cents / kW hour
- Assuming growth at 30% (10^{17} W hr in 22 years)

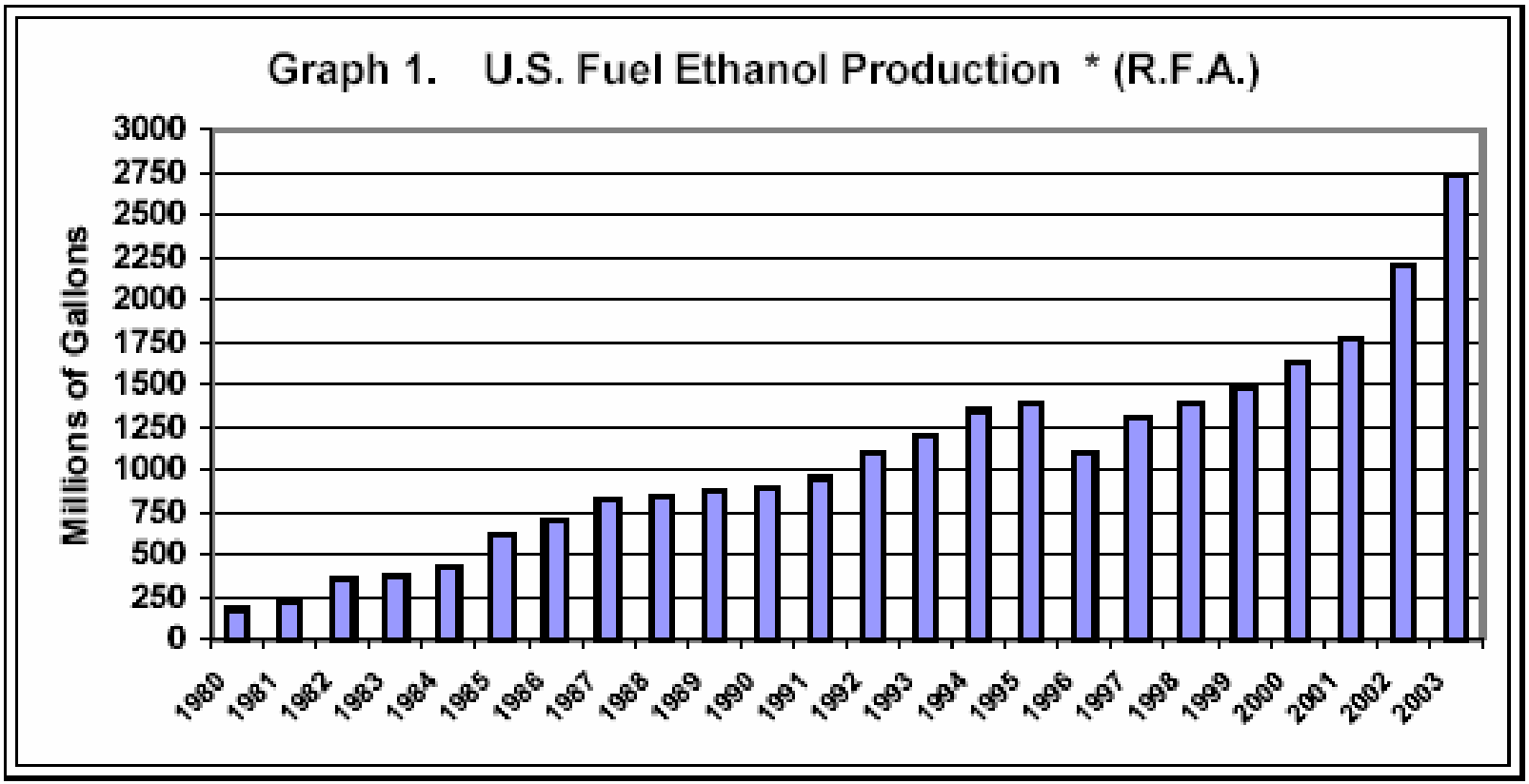
- Power from PV ~ 3×10^{13} W hr (3.2×10^{9} W)
- PV added (2003) ~ 7.5×10^{12} W hr (8.5×10^{8} W)
- Cost: \$8/watt (installed) in 2004 $\Rightarrow$ \$0.20/kWh
- Assuming growth at 30% (10^{17} W hr in 31 years)

Can we sustain this growth or will it flatten out much sooner?

Biomass (land+water use)

- Ferment starch $(C_6H_{10}O_5)_x$ in grain into ethanol
  - Corn kernel → 1/3 ethanol + 1/3 distiller's grain + 1/3 CO_2 (Starch → $C_6H_{12}O_6$ → $2C_2H_5OH + 2CO_2$)
  - 1 hectare . 120 days → 9 tons corn → 800 gallons ethanol → **14** Million watt hours
  - 1 hectare PV farm (5000 m^2 . 10% . 200w . 24hrs . 120 days) → **288** Million watt hours
- Cellulosic biomass (waste, wood) is "free" but less efficient

Ethanol: goal 5 billion barrels



Energy input in corn and ethanol production ≈ stored!
→Ethanol: a way to convert coal and gas into liquid fuel!

Summary of non-fossil

- **Nuclear:** bogged down by proliferation and waste issues
- **Biomass:** small and will peak at ~1%
- **Hydro:** most rivers tapped
- **Solar:** tiny but will grow as cost ⇩
- **Wind:** small but has potential for rapid growth

Transition to non-fossil

- **Mixed News (will buy US some time):**
  - **Coal is abundant in large economies**
  - **synthetic oil and gas is profitable for crude oil > $30 per barrel**
- **CO2: Sequestration or move away from fossil fuels**
- **Nuclear: Not yet a global solution**

NOT 3X

- **Renewables: Small. Exploit potential for rapid growth of wind and solar**

What I will bet on

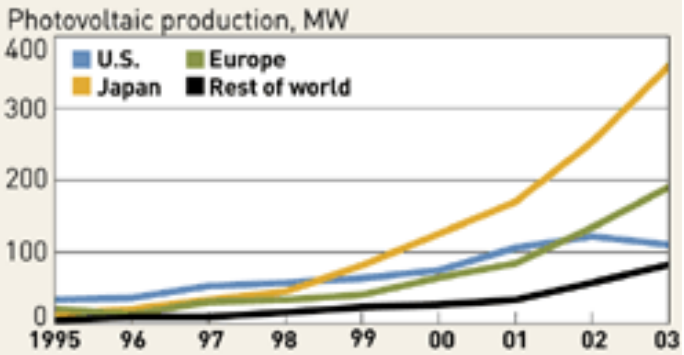
- **Oil** (will peak at ~86 million barrels/day: 2006)
- **Gas** (will peak around 2025. Fuel for Eurasia)
- **Coal** (will grow. Zero emissions only >> 2025)
- **Nuclear** (proliferation issues will limit growth)
- **Hydro** (no significant growth)
- **Wind** (will grow driven by market)
- **Solar** (will grow driven by home & building use)
- **Biomass** (useful for excess "corn" & waste disposal)

Long term vision: Dominant power will be electric with H_2 or CH_4 the intermediate carrier/storage

Electricity and gasoline in the US is cheap!

MANUFACTURE

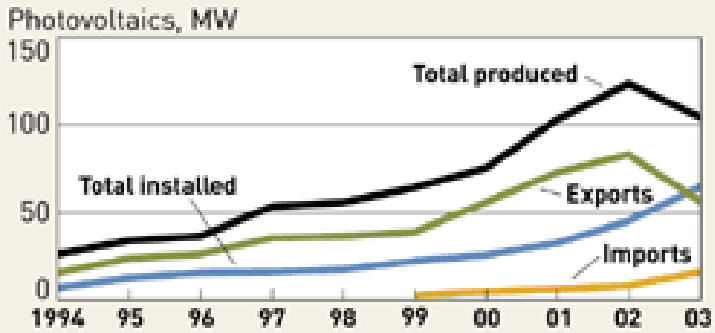
World leader in photovoltaic production is Japan



SOURCE: PV Energy Systems Inc.

U.S. SLIPS

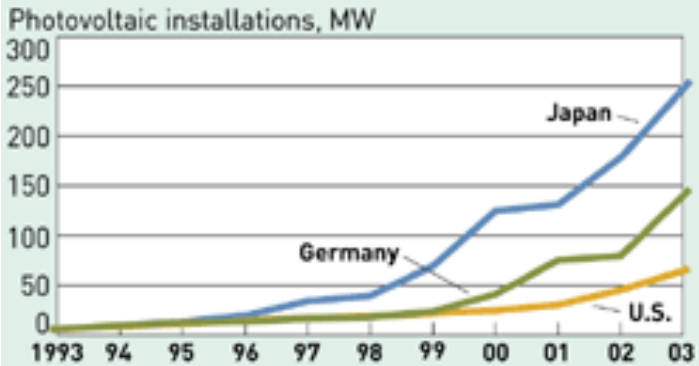
Production, export of photovoltaics decline



SOURCE: PV Energy Systems Inc.

APPLICATION

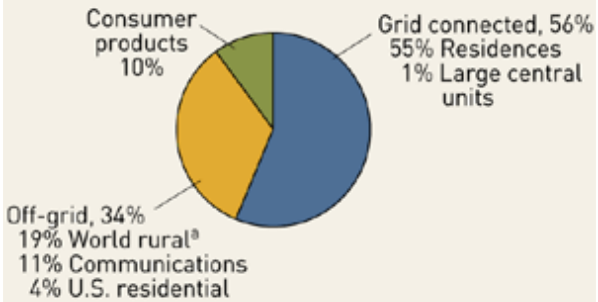
Japan leads in annual photovoltaic installations



SOURCE: Worldwatch Institute

MOSTLY ROOFTOPS

Residences use most of the photovoltaic-generated electricity



2003 world PV production = 744 MW

a Includes PV/diesel combinations. **PV** = photovoltaic
SOURCE: PV Energy Systems Inc.

Jeff Johnson, Chemical and Engineering News: June 21, 2004 Volume 82, Number 25 pp25-28

Recommendations

- **Education to change behavior: the oil and gas crisis is not a ploy by producing countries or companies. Global production is approaching its peak.**
- **Improve efficiency and conserve fossil fuels**
- **Increase CAFÉ standards by 1 mile / year for next 15 years and classify SUVs as automobiles**
- **Accelerate development of clean coal technology**
- **Accelerate development of solar and wind**
- **Reinvest in nuclear power. R&D in waste management**
- **Upgrade electric transmission grid**

Enlightened policy, incentives (rebates, credits) can have a major impact

Recognize inertia in energy sector

- Oil contracts, rigs, exploration technology
- Tankers and pipelines
- Refineries
- Auto industry
- 600 million cars running on gasoline
- Service stations and gasoline stations
- Existing coal electricity generation plants

The existing investment of >$10 trillion in oil cannot be changed overnight

Remember oil shocks, windows of opportunity, and lessons not learned

- Pre 1973
  - Controlled exploration & production, source nations just got royalty
- 1973 - 2001:
  - We don't own energy sources but dominate exploration & recovery
  - We bought it (traded for it) on favorable terms by providing security
- 2001 – 2020:
  - OCED does not own oil or gas reserves. Share of companies decreasing
  - many other nations are competing/trading for resources and rights
  - **All** cheap oil & gas reserves outside the Middle East are in decline
- **2020 –**
  - Middle East (if stable) holds the trump cards OR
  - Middle East is unstable & oil supplies insecure → development stalls
  - Middle East is occupied (Iraq is step one)

Promote American innovation and ingenuity. Reduce oil and gas imports by 1% every year!

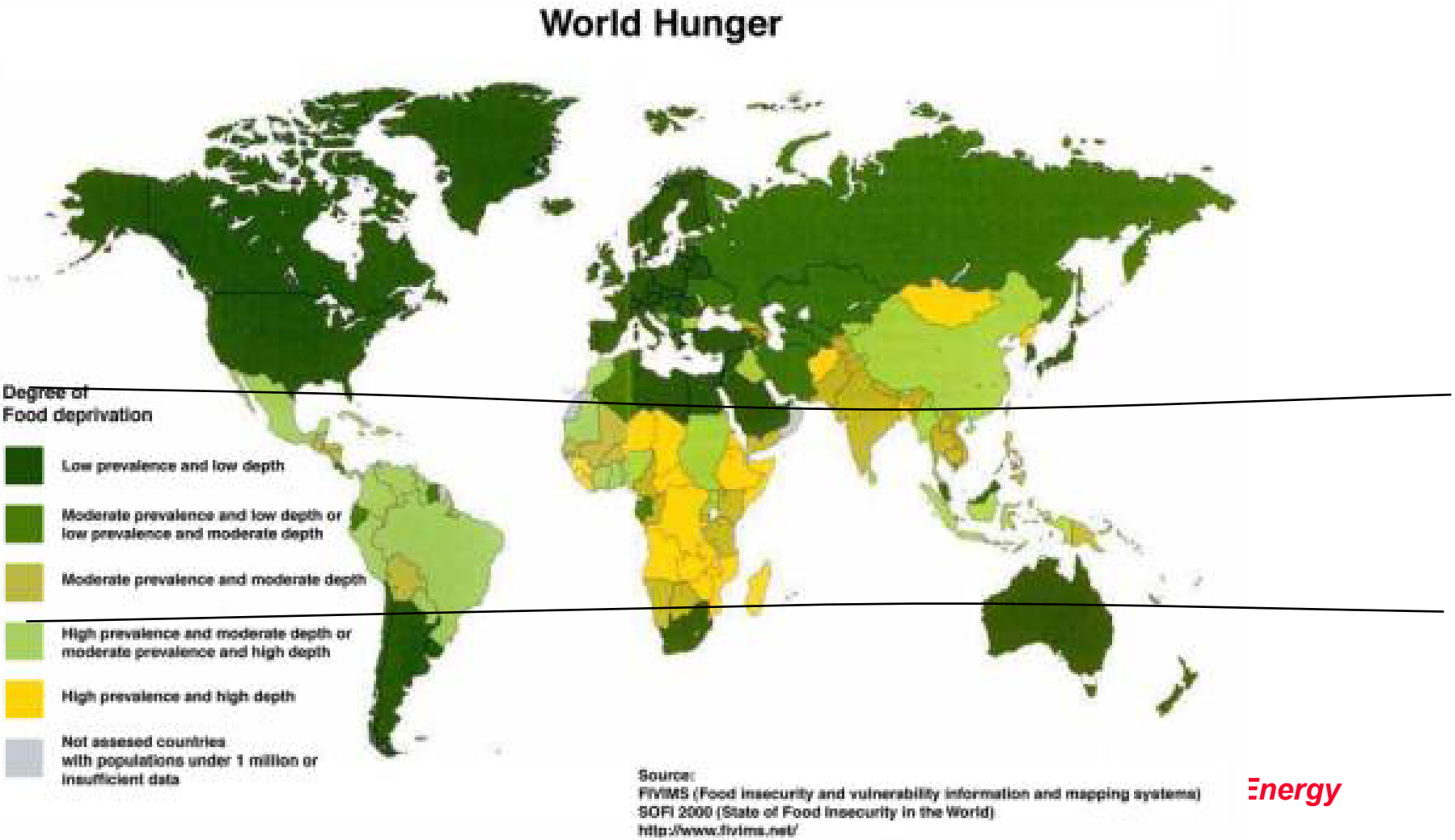
- Switch electricity generation to clean coal, nuclear and renewables. Share of renewables will increase as costs come down.
- Improve fuel efficiency in transport. In short term switch to efficient hybrid automobiles
- Re-examine centralized versus distributed power generation as clean coal and fuel cells technology develops
- Invest in broad based R&D

Make New Mexico a prototype for

- **Intelligent, designed, evolving mix**
- **Empowering incentives, credits, regulations**
- **Power grids that facilitate/embrace distributed and intermittent generation with attractive buy back offerings.**

Hope for the future!

Wind and solar are the most abundant sources of energy in poor countries lying within the tropics. Having exhausted oil and gas we owe them a clean, copious and cheap source.



Energy

Further reading and Sources

- http://www.eia.doe.gov/
- http://energy.cr.usgs.gov/oilgas/wep/wepindex_a.htm
- http://www.iea.org/
- http://www.nrel.gov/
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- "Hubbert's Peak", Kenneth Deffeyes, 2001
- "Out of Gas", David Goodstein, 2004
- "The end of oil", Paul Roberts, 2004
- "Blood and Oil", Michael T. Klare, 2004